[Sports Physical Therapy]

Periodization: Current Review and Suggested Implementation for Athletic Rehabilitation

Daniel S. Lorenz, DPT, PT, ATC/L, CSCS, USAW,*† Michael P. Reiman, PT, DPT, OCS, SCS, ATC, FAAOMPT, CSCS,‡ and John C. Walker, MPT, CSCS, CES, CGFI§

Background: Clinicians are constantly faced with the challenge of designing training programs for injured and noninjured athletes that maximize healing and optimize performance. Periodization is a concept of systematic progression—that is, resistance training programs that follow predictable patterns of change in training variables. The strength training literature is abundant with studies comparing periodization schemes on uninjured, trained, and untrained athletes. The rehabilitation literature, however, is scarce with information about how to optimally design resistance training programs based on periodization principles for injured athletes. The purpose of this review is to discuss relevant training variables and methods of periodization, as well as periodization program outcomes. A secondary purpose is to provide an anecdotal framework regarding implementation of periodization principles into rehabilitation programs.

Evidence Acquisition: A Medline search from 1979 to 2009 was implemented with the keywords *periodization*, *strength training*, *rehabilitation*, *endurance*, *power*, *hypertrophy*, and *resistance training* with the Boolean term *AND* in all possible combinations in the English language. Each author also undertook independent hand searching of article references used in this review.

Results: Based on the studies researched, periodized strength training regimens demonstrate improved outcomes as compared to nonperiodized programs.

Conclusions: Despite the evidence in the strength training literature supporting periodization programs, there is a considerable lack of data in the rehabilitation literature about program design and successful implementation of periodization into rehabilitation programs.

Keywords: periodization; undulating periodization; nonlinear periodization; linear periodization

Strength training is perhaps the most vital aspect of a rehabilitation program for any injury. Clinicians design programs that include several components, including endurance, flexibility, proprioception/kinesthesia, balance, joint and soft tissue mobility, speed, and power. A significant challenge lies in designing optimal training programs that facilitate neuro and muscular adaptations while being mindful of biological healing and the safety of the athlete. Strength training research is primarily based on healthy, trained, and/or untrained participants.[||] Additionally challenging is the need for constant monitoring of an athlete during the rehabilitation process. The clinician must consider that the athlete may not tolerate the systematic changes in training that come with progression through a protocol.

The strength training literature is often based on determining the 1-repetition maximum (1 RM), the maximum amount of weight that can be successfully lifted 1 time. Unfortunately, determining the 1 RM is contraindicated in those rehabilitating from an injury. Prediction models do exist for understanding the predicted 1 RM in healthy patients.[36,47,50,63] As in most studies in the strength and conditioning literature, the models are based on healthy participants. Rehabilitation programs are often performed when an athlete does not have his or her full range of motion and strength restored, which usually does not happen until the athlete is near the end stages. Loading is

||References 4, 7-9, 12, 15, 30, 32, 34, 36, 39, 41, 42, 45, 50, 54, 55, 60, 65, 67, 68, 69-71, 75, 76, 78, 79, 84-88, 91

From †Providence Medical Center, Kansas City, Kansas, ‡Wichita State University, Wichita, Kansas, and §Beacon Orthopedics, Cincinnati, Ohio
*Address correspondence to Daniel S. Lorenz, DPT, PT, ATC/L, CSCS, USAW, Providence Medical Center, 8929 Parallel Pkwy, Kansas City, KS 66112 (e-mail: dannyboylorenz@yahoo.com).
No potential conflict of interest declared.
DOI: 10.1177/1941738110375910

often a moving target based on pain and available ranges of movement. The clinician is left with a best-guess approach to determine the ideal resistance for the athlete.

Manipulating training variables to facilitate maximum gains—including sets, repetitions, load, and rest periods—can be daunting. Further complicating rehabilitation program design is poor agreement in the literature about the best way to rehabilitate an athlete while keeping these principles in mind. Last, the venue in which an athlete completes rehabilitation can cause programs to change as well. For example, a certified athletic trainer in a university setting will have fewer insurance limitations with an athlete, compared to a physical therapist in a private clinical setting. Therefore, these considerations may need to be reflected in program design.

A paucity of data regarding use of periodization models exists in the rehabilitation literature. Despite these limitations, several models of progressing athletes through training programs can be applied to rehabilitation. The review seeks to assimilate the available literature to provide a theoretical framework for the clinician to safely and effectively design programs for athletes recovering from injury.

RESISTANCE TRAINING PRINCIPLES

Load

Load is the amount of weight assigned to an exercise set. The load of an exercise program has often been characterized as the most critical aspect of a resistance training program.[4,25,52,77] An inverse relationship exists between the amount of weight lifted and the number of repetitions performed. Assigning a proper load in a resistance training program for the rehabilitating athlete depends on such factors as training experience, current level of fitness, and type of pathology. One or more of these loading schemes can be employed (depending on the athlete): increasing load based on 1 RM, increasing absolute load based on a targeted repetition number, and/or increasing loading within a prescribed zone (eg, 8-12 RM). A repetition maximum continuum has been supported.[5,18,23,84] The concept simply implies that specified loads are required for specific training effects. High-intensity training involves few repetitions, whereas low-intensity endurance training requires much higher repetitions (eg, 20-25 RM).

Volume

Training volume is a summation of the total number of repetitions performed during a training session multiplied by the resistance used (kilograms or pounds), and it reflects the duration of which muscles are being stressed.[81] Altering training volume can be accomplished by changing the number of repetitions performed per set, the number of sets per exercise, or the number of exercises per session.

The success of single-set versus multiple-set systems have been debated in regard to which provides superior results with respect to strength. Several studies have reported similar strength increases between single- and multiple-set programs,[19,34,74] whereas others have reported multiple-set programs being superior[9,12,69,76,79] in previously untrained subjects. The popularity of single-set training has grown among general fitness enthusiasts.[23] The current recommendation for novices is an initial 1 to 3 sets per exercise,[9,14,19,22,34,50,56,57] with progression to intermediate/advanced status requiring multiple-set use with systematic variation of volume and load over time.[36,39,45,46,65,71] An important aspect to consider with the rehabilitating athlete is that not all body parts or exercises need be performed with the same volume.

Progressive Overload

To continue making gains in an exercise program, stress to the muscle must be progressively increased as it becomes capable of producing greater force, power, or endurance. Once the muscles adapt to an exercise program workload, they will not continue to progress in the desired training goal unless the workload is increased in some manner. Therefore, to continually improve physiologic function, progressive increases in load must be applied to which adaptations will again occur.[43] If the athlete does not continue to adapt, he or she will eventually plateau and regress. Resistive exercises should be performed with enough frequency, load, and duration to produce overload without producing fatigue.[80]

There are several methods to progressively overload the muscle[2]—by increasing the resistance; by increasing the training volume by increasing the number of repetitions, sets, or exercises performed; by altering rest periods; or by increasing the repetition velocity during submaximal resistances. The most common method is that of increasing resistance/load.[25] Progressive overloading should gradually be introduced to the program. The athlete should have sufficient time to adapt before making significant changes. The American College of Sports Medicine[3] recommends that changes in total training volume (reps, sets, load) be made in increments of 2.5% to 5.0% per week to avoid the possibility of overtraining.

Training for Strength, Power, Hypertrophy, and Endurance

Training for each component requires careful and systematic planning, as well as critical analysis of the individual athlete's sport requirements. Different athletes on the same team sport can, and often do, require different training.

Strength. Strength is the ability of the muscle to exert force or torque at a specified or determined velocity.[38] Strength is an essential component of all rehabilitation and performance enhancement programs, and it can vary for different muscle actions.[40] Because all muscles function eccentrically, isometrically, and concentrically in the sagittal, frontal, and transverse planes, an integrated training program should utilize a multiplanar training approach using the entire muscle contraction spectrum and velocity contraction spectrum.[11,27,31,38]

Training for strength requires various levels of load, depending on the athletes. Using loads of 45% to 50% of 1 RM (and lower) has been shown to increase dynamic muscular strength in novice lifters.[14,78,84] Increased loads appear to be needed with progression. The novice to intermediate athlete should train with loads of 60% to 70% of 1 RM for 8 to 12 repetitions. A greater challenge is required for the more experienced lifters to gain strength. A load of 80% to 100% of 1 RM with a systematic progression of 1 to 3 sets per exercise for the novice lifters has been recommended to maximize muscular strength in the more advanced lifters.[¶]

Many sporting activities take place so rapidly that it is virtually impossible to recruit the maximum number of muscle fibers. Therefore, many activities do not depend solely on the ability to produce maximum strength; rather, these sports depend on the athlete's ability to produce power.[11,27,74]

Power. Power is defined as work per unit of time: [force × (distance/time)]. Because the definition of velocity is (distance/time), power can further be defined as (force × velocity). Time is an essential element when training for power. Rate of force development can be defined as the rate at which strength increases.[74] It is the most important neural adaptation for the majority of athletes.[17]

Training programs dedicated to the development of power require high-force training and high-quality power movements in which time and the rapidity of movements play a vital role in the quality of the exercise.[25] When athletes plateau in strength development or are required to produce strength more quickly, specialized power training appears to be even more important to optimize power development.[7,54] Athletes cannot be powerful without being relatively strong.[86]

Advanced athletes require training with heavy loads (85% to 100% of 1 RM) with light loads (30%) at high speeds to develop optimal levels of speed strength (power).[49,87] The 30% RM load level was found to be superior to plyometric training and traditional weight training (80% to 90% of 1 RM) in developing dynamic athletic performance.[87]

Plyometrics is a popular training method based on the stretch-reflex properties of the muscle to produce power.[16,61] Owing to the high physical demands of plyometric training, a baseline level of strength should be achieved before its implementation.[16,62,82] It is also recommended that power training be performed only 2 to 3 days per week for novices and up to 4 to 5 days per week for advanced athletes.[16,61,62] Rest intervals should be long enough to allow maximum effort on subsequent sets (from 5-10 seconds to 2-4 minutes), and recovery between training sessions should be at least 2 days—preferably, 4 days.[2]

Hypertrophy. Hypertrophy can be simply defined as an increase in muscle size. Larger training volumes are needed when the goal of a resistance training program is that of increased lean body mass or muscular hypertrophy.[25,77] For novice to intermediate lifters, moderate loads (70%-85% of 1 RM) of 8 to 12 repetitions per set for 1 to 3 sets per exercise are recommended.[62] Advanced lifters increase the load (70%-100% of 1 RM) and the volume with an increased number of sets (3 to 6) in a periodized manner with emphasis on higher repetitions.[62] Bompa proposed using similar loads for hypertrophy of muscle, except repetitions to fatigue in lieu of 12 repetitions.[11] For novice lifters, training 2 to 3 days per week is recommended and up to 4 to 6 days per week for advanced lifters.[62] A key component of a muscle hypertrophy training program is that of machine and free motion weights incorporating predominantly total body activity.[62]

Endurance. Endurance is the ability to work for prolonged periods: the ability to resist fatigue.[51,85] Muscle endurance is the ability of a local isolated muscle group to perform repeated contractions over a period.[51] Muscular endurance training has a positive transfer to cardiovascular endurance.[79]

Generally, endurance training is of lower intensity and higher volume in comparison to training for strength and power. As many as 30 to more than 150 repetitions (depending on load percentage of 1 RM) has been suggested.[11] For novice to intermediate individuals, the consensus recommendation is that of relatively light loads with moderate to high volume. Recommendations for advanced individuals include various loading strategies for multiple sets per exercise (10-25 repetitions or more) in a periodized manner leading to a higher overall volume using lighter loads.[62]

HISTORICAL PERSPECTIVE OF RESISTANCE TRAINING MODELS

As early as 1948, DeLorme[21] recommended (1) heavy resistance and low repetitions to develop strength and (2) light resistance with a high repetitions to develop muscular endurance.[6,21] Three sets of 10 RM with progressive loading during each set was proposed. Conversely, the Oxford technique[24] uses a regressive loading model for resistance exercise. The programs share similarities: rest periods and increases in resistance over time. The DeLorme technique builds a warm-up into the protocol, whereas in the Oxford technique, resistance is progressively decreased as fatigue surfaces. The Oxford technique starts at 10 RM and removes weight, whereas in the DeLorme method, weights are added to achieve 10 RM. Fish and coauthors[24] compared the Oxford and DeLorme techniques for training efficacy. In a randomized prospective study comparing the 2 techniques over a 9-week time frame, the DeLorme technique was more effective for a 10-RM increase, although the differences were not statistically significant.[24] No significant sex differences were found.

The daily adjustable progressive resistance exercise (DAPRE) technique was clinically developed in an effort to provide an objective means of increasing resistance with strength increases during knee rehabilitation postinjury/surgery.[37] The key to the DAPRE technique is that on the third and fourth sets of exercise, the patient performs as many repetitions as possible. The number performed on those sets determines the

¶References 14, 30, 36, 40, 45, 56, 58, 65, 66, 68, 71, 78, 84 amount of weight added (or sometimes removed) for the next session. During the first set of the DAPRE technique, half the maximum weight is performed 10 times. For the second set, 6 repetitions are performed at 75% of the maximum weight. In the third set, the maximum weight is lifted to fatigue. Weight is reduced 5 to 10 lb (2.25-4.50 kg) if the athlete can lift the weight only a few times. The weight stays the same if he or she can perform 5 or 6 repetitions. If the athlete can perform more than 6 repetitions, the following set will include a 5- to 10-lb (2.25- to 4.50-kg) increase. When this technique was utilized in 21 athletes after knee immobilization, they averaged an increase of 4.3 ± 2.2 kg resistance per day for a period of 6.4 ± 2.2 days for a 6-RM test.[20]

A study of 21 women used isotonic and isokinetic exercises to determine strength increases during a 1-legged jump.[20] Both training groups used a leg press protocol 3 days a week for 5 weeks. The isokinetic group trained with 2 sets of 10 repetitions through a velocity spectrum, and the isotonic group trained with the DAPRE technique. Both groups increased strength, but the 1-legged jump did not change. Wawryzniak and colleagues[83] observed no changes in hop test performance with the DAPRE technique in participants who performed unilateral leg presses 3 times per week for 6 weeks—one group from 0° to 60° and the other from 0° to 90°.

In the 1950s, Norwegian physiotherapist Oddvar Holten developed the philosophy of medical exercise therapy as a method of determining training intensity.[33] The Holten curve (Figure 1) is a scale of the percentage of intensity correlated with repetitions performed. The athlete performs a weight to fatigue; the number of repetitions performed are then correlated with a given intensity, and a 1 RM is determined. For example, if a patient can do 10 lb (4.50 kg) for 16 repetitions (75%), then 10 is divided by 0.75 for a 1 RM of 13.3 lb (5.99 kg). For an elderly patient, the 1 RM is multiplied by 80% (13.3 × 0.80 = 10.5 lb [4.73 kg]). This patient would perform 3 sets of 10 at 10.5 lb (4.73 kg) every other day (Figure 1).

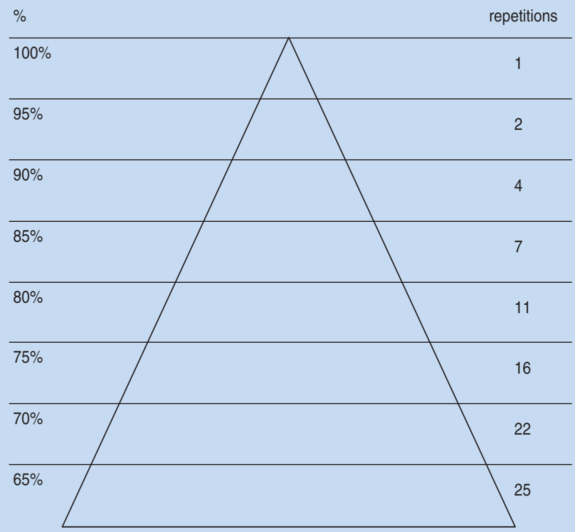

Figure 1. The Holten curve. Percentage of 1-repetition maximum (1 RM) on the left side of the curve with estimated repetitions at that intensity on the right. Used with permission from Oostdam N et al. Design of FitFor2 study: the effects of an exercise program on insulin sensitivity and plasma glucose levels in pregnant women at high risk for gestational diabetes. *BMC Pregnancy and Childbirth.* 2009;9:1.

PERIODIZATION

Periodization is one way for the clinician to approach the design of resistance training programs. Periodization is the planned manipulation of training variables (load, sets, and repetitions) to maximize training adaptations and prevent the onset of overtraining syndrome.[13] Some form of periodization is usually needed for maximal strength gains to occur,[13,25,26,44,57,67,77,85] although contrary data do exist.[8,70] Periodization can be traced to Selye's general adaptation syndrome (ie, systems will adapt to any changes they might experience in an attempt to meet the demands of the stressors).[64,72] The goal of a periodized program is to optimize the principle of overload, the process by which the neuromuscular systems adapt to unaccustomed load or stressors.[59,62] The training program specifies the intensity, volume, and frequency; the interactions of these variables result in the overload.[6] For the neuromuscular system to maximally adapt to the training load or stress, volume and intensity alterations are necessary. Owing to the increased demands, the neuromuscular system adapts with increases in muscular performance. If the system is allowed to adapt to stressors without concomitant changes in overload, no further adaptations are needed, and increases in the desired outcome will eventually stop.[67,66] Conceptually, periodization helps avoid this problem because the load on the neuromuscular system is constantly changing. Furthermore, periodization may be beneficial by adding variation to workouts, thus avoiding boredom or training plateaus (Figure 2).[67,66]

Although other models of periodization exist, there are 2 primary models. First, the classic, or linear, model is based on changing exercise volume and load across several predictable mesocycles. This model was developed by Russian scientist Leo Matveyev[49] and supported by Stone[77] and Bompa.[11] Based on a 12-month period, the program is referred to as a macrocycle; the 2 subdivisions are the mesocycle (3-4 months) and the microcycle (1-4 weeks). The other main model is the undulating periodization model, first proposed by Poliquin.[59] The term *nonlinear periodization* has become more favorable compared to *undulating periodization*. Nonlinear periodization is based on the concept that volume and load are altered more frequently (daily, weekly, biweekly) to allow the neuromuscular system more frequent periods of recovery. Phases are much shorter, providing more frequent changes in stimuli, which may be highly conducive to strength gains.[59] Kraemer and Fleck[41] expanded this concept by including planned versus flexible nonlinear periodization. The planned model follows predicted loading

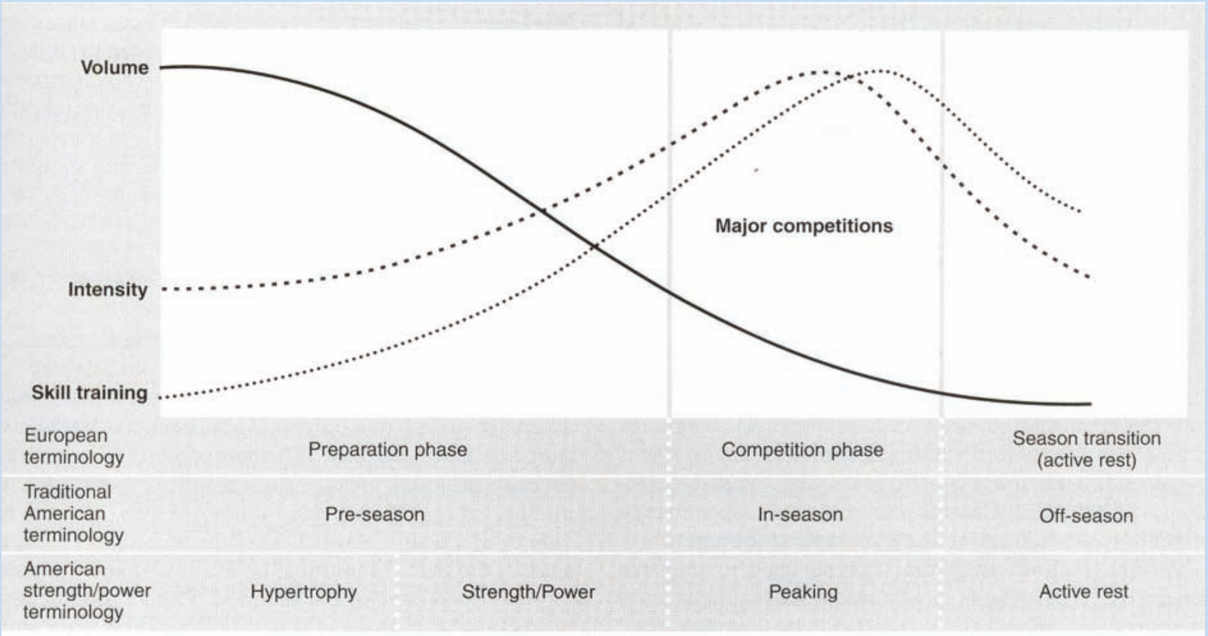

Figure 2. Periodization of strength training with associated terminology used in European and American literature. Note the inverse relationship of intensity and volume. Used with permission from Gearhart RF Jr et al.

schemes, but the flexible plan allows the clinician to adjust the plan based on the status of the athlete. Last, reverse linear periodization (RLP) follows the modifications in load and volume but in reverse order: increasing volume and decreasing load.[68]

Periodization can be accomplished by manipulating sets, repetitions, exercise order, number of exercises, resistance, rest periods, type of contractions, and training frequency,[25,64] thereby providing numerous periodization programs. Manipulating variables is arguably the greatest challenge that clinicians face when designing and modifying resistance training programs.

Periodization Models

A review of the studies examining nonlinear periodization and undulating periodization training programs demonstrates that daily program manipulation is more beneficial than nonperiodized training for eliciting strength gains.[32] Comparisons between linear and nonlinear periodization models are quite limited.[32]

Prestes et al[60] compared linear periodization (LP) and RLP to determine the effects on maximal strength and body composition in previously trained women while using loads between 4 and 14 RM. This study was the first to examine such high intensities. Athletes trained for 12 weeks using each periodization model. The LP group's training load increased every 1 to 4 weeks, whereas the volume decreased. Thus, the intensity increased every week for the LP group and decreased in the RLP group. Recovery was implemented by decreasing the load to 12 RM at the 4th, 8th, and 12th weeks as well as by decreasing their frequency from 3 to 2 sessions per week. LP and RLP both increased maximal strength for the upper and lower body. Greater percentage increase in maximal strength in the upper and lower body was found with LP training compared to RLP. The LP group demonstrated improvements in body composition by decreasing body fat and increasing fat-free mass, which was not observed with the RLP group. Compared to RLP, LP presented more positive effects on body composition and maximal strength when intensity was between 4 and 14 RM.

Baker et al[8] compared the effectiveness of 3 periodization models (nonperiodized control, LP, undulating periodization) on maximal strength and vertical jump in 22 previously trained men performing a 12-week strengthening program 3 days per week. In a short-term training cycle, nonlinear periodization resulted in the same gains as the LP and undulating periodization. Additionally, the mechanisms contributing to the development of strength and power were different. Improvements in maximal strength did not necessarily equate to improvements in power activities such as jumping, thus clearly highlighting the specificity of training.[7]

Buford et al[13] compared periodization models during a 9-week training program with equated volume and intensity for strength. They compared LP, daily undulating periodization (DUP), and weekly undulating periodization. The training program for each group was 9 weeks with a frequency of 3 times per week. Athletes were tested at 4 weeks to adjust their 1 RM. Five weeks later, they were tested again to compare the results. Although all 3 groups improved strength, no significant differences were found between the groups.

Rhea et al[68] compared LP, RLP, and DUP with equated volume and intensity for local muscular endurance. Participants performed 3 sets of leg extensions 2 days per week. The LP group performed sets of 25 RM, 20 RM, and 15 RM, changing every 5 weeks. The RLP group progressed in the reverse order. The DUP group changed between each workout: 25 RM, 20 RM, and 15 RM, repeated for the 15 weeks. All 3 models increased local muscular endurance. The RLP group demonstrated greater endurance improvements than did the LP and DUP groups.

Rhea et al[67] also compared the effects on strength between a LP group and a DUP group. Lower intensities were used as compared to those of Prestes et al.[60] Their training involved 3 sets of bench press and leg press, 3 days per week for 12 weeks. The LP group changed its intensity at weeks 4 and 8, whereas the DUP group changed on a daily basis (Monday, Wednesday, and Friday). Both groups demonstrated increased strength, but the DUP group did elicit higher strength gains.

Hoffman et al[32] compared periodization models, including a nonperiodized LP group and a planned nonlinear periodization group, using trained American football players. All athletes participated in a 15-week off-season conditioning program. No significant difference was found between the groups.

Application of Periodization in Rehabilitation

Rehabilitation programs have traditionally used a basic progressive overload approach primarily focusing on the injured area. Periodized training is a safe method of training for older adults as well as those in pain.[30,35] Although the following commentary has not been validated in peer-reviewed literature and is anecdotal, it may stimulate further studies.

What is consistently lacking in rehabilitation protocols are specific guidelines on the resistance training variables. The clinician has general goals for each phase, precautions, and a vague incomplete list of exercises to be performed. Studies have compared eccentric training to a standard rehabilitation protocol after an ACL reconstruction,[28] open versus closed chain exercises in ACL-deficient knee rehabilitation[90] and patellofemoral pain,[88] and even home versus physical therapy–supervised rehabilitation based on a standard rehabilitation protocol.[29] An accelerated program (19 weeks) has been compared to a nonaccelerated version (32 weeks) after an ACL reconstruction.[10] The protocols were identified but did not detail the exercises performed and the stage of the rehabilitation process. There was no discussion of resistance training variables.

In studies on ACL reconstruction, several options exist. Besides comparing linear versus nonlinear models using the standard rehabilitation protocol, researchers could compare modes or duration of training. Using linear and nonlinear periodization[67,68] as a framework, researchers could divide the ACL reconstructions into 1 of 3 groups: control, linear, and nonlinear. Traditional rehabilitation programs could be compared to eccentrically based programs, or eccentrics could be used in the periodization models.

Alfredson et al[1] proposed a rehabilitation program for Achilles tendinopathy employing periodization principles, which has successfully been used in later studies of this injury.[48,55,73] In a prospective study of 15 athletes with chronic Achilles tendinosis, participants performed 3 sets of 15 eccentric repetitions of bent- and straight-knee calf raises, twice a day, 7 days per week over 12 weeks. Athletes were told to work through pain, only stopping if it became disabling. Once body weight was pain-free, load was increased in 5-kg increments with use of a backpack. All 15 participants returned to preinjury levels of activity with a significant decrease in pain and increase in strength.

Only 2 studies have compared resistance training programs in a rehabilitation setting; one was among healthy participants. Wong et al[89] used 2 weight training programs for patellar stabilization in healthy participants in a control group. Each group did parallel squats and knee extensions, 3 times per week for 8 weeks. Resistance was determined after momentary muscle failure was reached after each set of exercises. If participants were able to perform more repetitions, resistance was increased by 5 lb (2.25 kg) and vice versa (ie, decreased upon inability to perform). One training group completed a strength program of 5 sets of 5 repetitions with 2 minutes of rest between sets, whereas the other group performed a hypertrophy program at 4 sets of 10 repetitions with 1-minute rest between sets. Both training groups had comparable gains in vastus medialis oblique size, passive patellar stability, and knee extension force—all greater than that of the control group.

Kell et al[35] compared 2 forms of periodized musculoskeletal rehabilitation based on whole body training among patients with chronic low back pain to determine its influence on musculoskeletal health, pain, disability, and quality of life. One group used an LP resistance training program based on 10 RM, whereas the other used aerobic training. Both forms of training induced meaningful changes in strength, endurance, flexibility, and power, as well as aerobic fitness. The resistance training was more efficacious for chronic low back pain. Body composition improved; pain and disability were reduced; and quality of life was recovered. These protocols are loosely based on periodization principles with specific goals at each phase of rehabilitation, much like traditional strength training. A flexible nonlinear periodization model can account for unexpected changes in a patient's status where the clinician may need to alter the intensity, volume, training focus (strength, endurance, power), and so on for a particular time frame (eg, day, week, month).

In a postsurgical ACL reconstruction patient, endurance, hypertrophy, strength, and power days can be developed, depending on the timeline using a 3-day-per-week program. When an athlete progresses to more sport-specific drills (plyometrics and agility) in the later stages of rehabilitation, emphasis can shift to strength, power, and hypertrophy sessions. In the final stages of rehabilitation before return to sport, power, strength, or hypertrophy can be emphasized on the basis of the athlete's deficits. If an athlete has persistent quadriceps deficits, hypertrophy sessions may be beneficial (Tables 1 and 2).

Table 1. Linear periodization following anterior cruciate ligament reconstruction.[a]

Weeks 4-8: Endurance Phase	Rest, 30-45 s
Straight leg raises	3 × 15-20
Side-lying leg raises	3 × 20-30
Supine bridges	3 × 20-30
Clamshells	3 × 20-30
Crabwalk	3 × 15 steps each direction
Leg press	3 × 15-20
Step ups	3 × 15-20
Dumbbell squats	3 × 15-20
Prone leg curl	3 × 15-20
Physioball bridge	3 × 15-20
Single-leg wall jumps	3 × 12 each leg
Bounding	3 × 6-8 each leg
Tuck jumps	3 × 3-5
Depth jumps	3 × 3
Weeks 8-12: Hypertrophy Phase	**Rest, 45 s to 1 min**
Leg press	3-4 sets × 12 repetitions (or failure)
Step ups	3-4 sets × 10-12
Dumbbell squats	3-4 sets × 10-12
Lunges	3-4 sets × 10-12
Single leg squats	4 × 12
Prone leg curl	4 × 12
Physioball bridge	4 × 12
Physioball curl	4 × 12
Weeks 12-16: Strength Phase	**Rest, 2-3 min**
Barbell back squats / front squats	3-4 sets × 6-10
Dead lift	3-4 sets × 6-10
Leg press	3-4 sets × 6-10
Lunges	3-4 sets × 6-10
Nordic hamstring	3-4 sets × 6-10
Prone leg curl	4 × 8-12
Physioball bridge / curl / curl to bridge	3 × 6-10 each
Weeks 16-24: Conversion to Power	**Rest, 3-5 min**
Hang clean	3 × 3-5
Power clean	3 × 3-5
Jump shrugs	3 × 3-5
Squat jumps	3 × 6
Scissor jumps	3 × 4 each leg
Lateral leaps	3 × 6
Box jumps	3 × 6

(continued)

Table 1. (continued)

[a]Assumptions include no associated pathologies and no effusion. All exercises are not necessarily performed in every session. Exercises are only suggested to illustrate the objectives of each phase. We suggest using balance/proprioceptive exercises as an active recovery during rest periods. Loads in each phase are at a level sufficient for client to perform the required repetitions only. The load is either increased or decreased, depending on the client's success in achieving the repetition requirement, as well as his or her ability to perform the exercise safely.

Table 2. Nonlinear periodization program.[a]

Weeks 4-8
Setting foundation with emphasis on muscle endurance
Monday: Endurance
Wednesday: Hypertrophy
Friday: Strength
Weeks 8-12
Emphasis on increasing muscle size and continued strength training
Monday: Hypertrophy
Wednesday: Strength
Friday: Hypertrophy
Weeks 12-16
Strength gain emphasis prior to transition to power training
Monday: Strength
Wednesday: Endurance
Friday: Strength
Weeks 16-20
Begin transition to power
Monday: Strength
Wednesday: Power
Friday: Strength
Weeks 20-24
Continued progression of strength and power phases of rehabilitation
Monday: Power
Wednesday: Strength/Hypertrophy
Friday: Power

[a]See Table 1 for sample exercises and loads. Exercises are suggested only to illustrate the objectives of each phase. We suggest using balance/proprioceptive exercises as an active recovery during rest periods.

Clinical Recommendations

SORT: Strength of Recommendation Taxonomy
A: consistent, good-quality patient-oriented evidence
B: inconsistent or limited-quality patient-oriented evidence
C: consensus, disease-oriented evidence, usual practice, expert opinion, or case series

Clinical Recommendation	SORT Evidence Rating
Periodized programs elicit greater strength gains than nonperiodized programs.**	A

**References 4, 7-9, 13-15, 26, 32, 34, 35, 40, 44, 53, 58, 60, 64, 66-68, 70, 76, 78, 79, 85
For more information about the SORT evidence rating system, see www.aafp.org/afpsort.xml and Ebell MH, Siwek J, Weiss BD, et al. Strength of Recommendation Taxonomy (SORT): a patient-centered approach to grading evidence in the medical literature. *Am Fam Physician*. 2004;69:549-557.

In LP (Table 1), phases depend on the time frame of the rehabilitation program. Once the patient reaches the fourth postoperative week after the ACL reconstruction, the emphasis should be on muscle endurance. This provides the baseline for hypertrophy and strength; power training will eventually be implemented. The hypertrophy phase should be implemented around the eighth postoperative week because initial muscular gains are due to neuromuscular efficiency mechanisms as opposed to muscular hypertrophy. Strength training should be the emphasis between the 12th to 16th week before power-type training.[16,62,82] In the power phase of a program, 2 sessions a week are sufficient while still providing adequate recovery between sessions.

In the nonlinear program (Table 2), there is still an emphasis on a parameter (endurance, strength, power, etc.) while allowing for increased flexibility. The earliest weeks primarily emphasize endurance, although hypertrophy and strength are introduced. In weeks 8 to 12, the emphasis is on augmenting muscle size similar to the linear program. The overall goals are also similar in both programs.

In summary, the concept of periodization in terms of strength training has shown promise in strength and conditioning on healthy trained and untrained athletes.[#] There is a paucity of data in rehabilitation research using the principles of periodization in the design of rehabilitation programs.

Periodized strengthening programs elicit greater strength gains than do nonperiodized programs. There are no significant differences in strength gains when volume and intensity are equated between LP and nonlinear periodization in untrained and trained individuals, whether men or women. Exercise intensity is the most important variable for stimulating muscle growth.

[#]References 4, 7-9, 13-15, 26, 32, 34, 35, 40, 44, 53, 58, 60, 64, 66-68, 70, 76, 78, 79, 85

REFERENCES

1. Alfredson H, Pietila T, Jonsson P, Lorenzton R. Heavy-load eccentric calf muscle training for the treatment of chronic Achilles tendinosis. *Am J Sports Med*. 1998;26:360-366.
2. Allerheiligen WB. Speed development and plyometric training. In: Baechle TR, ed. *Essentials of Strength Training and Conditioning*. Champaign, IL: Human Kinetics; 1994:314-344.
3. American College of Sports Medicine. Position stand: progression models in resistance training for healthy adults. *Med Sci Sports Exerc*. 2002;34:364-380.
4. Anderson T, Kearney JT. Effects of three resistance training programs on muscular strength and absolute and relative endurance. *Res Q Exerc Sport*. 1982;53:1-7.
5. Atha J. Strengthening muscle. *Exerc Sport Sci Rev*. 1981;9:1-73.
6. Bagenhammer S, Hansson EE. Repeated sets or single sets of resistance training: a systematic review. *Adv Physiother*. 2007;9:154-160.
7. Baker D. A series of studies on the training of high-intensity muscle power and rugby league football player. *J Strength Cond Res*. 2001;15:198-209.
8. Baker D, Wilson G, Carolyn R. Periodization: the effect on strength of manipulating volume and intensity. *J Strength Cond Res*. 1994;8:235-242.
9. Berger RA. Effect of varied weight training programs on strength. *Res Q Exerc Sport*. 1962;33:168-181.
10. Beynnon BD, Uh BS, Johnson RJ, et al. Rehabilitation after anterior cruciate ligament reconstruction: a prospective, randomized, double-blind comparison of programs administered over two different time intervals. *Am J Sports Med*. 2005;33:347-359.
11. Bompa TO. *Theory and Methodology of Training: The Key to Athletic Performance*. Dubuque, IA: Kendall/Hunt; 1994.
12. Borst SE, Dehoyos DV, Garzarella L, et al. Effects of resistance training on insulin-like growth factor-1 and IGF binding proteins. *Med Sci Sports Exerc*. 2001;33:648-653.
13. Buford TW, Rossi SJ, Smith DB, Warren AJ. A comparison of periodization models during nine weeks with equated volume and intensity for strength. *J Strength Cond Res*. 2007;21:1245-1250.
14. Campos GE, Luecke TJ, Wendeln HK, et al. Muscular adaptations in response to three different resistance-training regimens: specificity of repetition maximum training zones. *Eur J Appl Physiol*. 2002;88:50-60.
15. Capen EK. Study of four programs of heavy resistance exercises for development of muscular strength. *Res Q Exerc Sport*. 1956;27:132-142.
16. Chu DA. *Jumping Into Plyometrics*. Champaign, IL: Human Kinetics; 1992.
17. Clark MA. *Integrated Training for the New Millennium*. Thousand Oaks, CA: National Academy of Sports Medicine; 2001.
18. Clarke DH. Adaptations in strength and muscular endurance resulting from exercise. *Exerc Sport Sci Rev*. 1973;1:73-102.
19. Coleman AE. Nautilus vs universal gym strength training in adult males. *Am Correct Ther J*. 1977;31:103-107.
20. Cordova ML, Ingersoll CD, Kovaleski JE, Knight KL. A comparison of isokinetic and isotonic predictions of a functional task. *J Athl Train*. 1995;30:319-322.
21. DeLorme TL. Restoration of muscle power by heavy resistance exercise. *J Bone Joint Surg*. 1945;27:645-667.

22. Dudley GA, Djamil R. Incompatibility of endurance- and strength-training modes of exercise. *J Appl Physiol.* 1985;59:1446-1451.
23. Feigenbaum MS, Pollock ML. Prescription of resistance training for health and disease. *Med Sci Sports Exerc.* 1999;31:38-45.
24. Fish DE, Krabak BJ, Johnson-Greene D, DeLateur BJ. Optimal resistance training: comparison of DeLorme with Oxford techniques. *Am J Phys Med Rehabil.* 2003;82:903-909.
25. Fleck SJ, Kraemer WJ. *Designing Resistance Training Programs.* 3rd ed. Champaign, IL: Human Kinetics; 2004.
26. Fleck SJ. Periodized strength training: a critical review. *J Strength Cond Res.* 1999;13:82-89.
27. Fleck SJ, Schutt RC. Types of strength training. *Clin Sports Med.* 1985;4:159-167.
28. Gerber JP, Marcus RL, Dibble LE, et al. Effects of early progressive eccentric exercise on muscle structure after anterior cruciate ligament reconstruction. *J Bone Joint Surg Am.* 2007;89:559-570.
29. Grant JA, Mohtadi NG, Maitland ME, et al. Comparison of home versus physical therapy-supervised rehabilitation programs after anterior cruciate ligament reconstruction: a randomized clinical trial. *Am J Sports Med.* 2005;33:1288-1296.
30. Häkkinen K, Alen M, Komi PV. Changes in isometric force-and relaxation-time, electromyographic and muscle fibre characteristics of human skeletal muscle during strength training and detraining. *Acta Physiol Scand.* 1985;125:573-585.
31. Harman E. The biomechanics of resistance exercise. In: Baechle TR, ed. *Essentials of Strength Training and Conditioning.* Champaign, IL: Human Kinetics; 1994:65-92.
32. Hoffman J, Ratamess N, Klatt M, et al. Comparison between different off-season resistance training programs in Division III American college football players. *J Strength Cond Res.* 2009;23;11-19.
33. Holten Institute. http://www.holteninstitute.com. Accessed March 26, 2009.
34. Jacobson BH. A comparison of two progressive weight training techniques on knee extensor strength. *J Athl Train.* 1986;21:315-319.
35. Kell R, Asmundson G. A comparison of two forms of periodized exercise rehabilitation programs in the management of chronic nonspecific low-back pain. *J Strength Cond Res.* 2009;23:513-523.
36. Kemmler WK, Lauber D, Engelke K, Weineck J. Effects of single- vs multiple-set resistance training on maximum strength and body composition in trained postmenopausal women. *J Strength Cond Res.* 2004;18:689-694.
37. Knight KL. Quadriceps strengthening with the DAPRE technique: case studies with neurological implications. *Med Sci Sports Exerc.* 1985;17:646-650.
38. Knuttgen HG, Kraemer WJ. Terminology and measurement in exercise performance. *J Appl Sport Sci Res.* 1987;1:1-10.
39. Kraemer WJ. A series of studies-the physiological basis for strength training in American football: fact over philosophy. *J Strength Cond Res.* 1997;11:131-142.
40. Kraemer WJ. Involvement of eccentric muscle action may optimize adaptations to resistance training. *Sport Sci Exchange.* 1992;4(41):230-238.
41. Kraemer WJ, Fleck SJ. *Optimizing Strength Training: Designing Non-linear Periodization Workouts.* Champaign, IL: Human Kinetics; 2007.
42. Kraemer WJ, Hakkinen K, Triplett-Mcbride NT, et al. Physiological changes with periodized resistance training in women tennis players. *Med Sci Sports Exerc.* 2003;35:157-168.
43. Kraemer WJ, Newton RU. Training for muscular power. *Phys Med Rehabil Clin North Am.* 2000;11:341-368.
44. Kraemer WJ, Ratamess NA. Fundamentals of resistance training: progression and exercise prescription. *Med Sci Sports Exerc.* 2004;36:697-688.
45. Kraemer WJ, Ratamess N, Fry AC, et al. Influence of resistance training volume and periodization on physiological and performance adaptations in college women tennis players. *Am J Sports Med.* 2000;28:626-633.
46. Kramer JB, Stone MH, O'Bryant HS, et al. Effects of single vs multiple sets of weight training: impact of volume, intensity, and variation. *J Strength Cond Res.* 1997;11:143-147.
47. Kravitz L, Akalan C, Nowicki K, Kinzey SJ. Prediction of 1 repetition maximum in high-school power lifters. *J Strength Cond Res.* 2003;17:167-172.
48. Langberg H, Ellingsgaard H, Madsen T, et al. Eccentric rehabilitation exercise increases peritendinous type I collagen synthesis in humans with Achilles tendinosis. *Scand J Med Sci Sports.* 2007;17:61-66.
49. Matveyev L. *Fundamentals of Sports Training.* Moscow: Progress; 1981.
50. Mayhew JL, Gross PM. Body composition changes in young women with high resistance training. *Res Q Exerc Sport.* 1974;45:433-440.
51. McCardle WD, Katch FI, Katch VI. *Exercise Physiology: Energy, Nutrition, and Human Performance.* 4th ed. Baltimore, MD: Lippincott Williams & Wilkins; 1996.
52. McDonagh MJN, Davies CTM. Adaptive responses of mammalian skeletal muscle to exercise with high loads. *Eur J Appl Physiol.* 1984;52:139-155.
53. Newton RU, Kraemer WJ. Developing explosive muscular power: implications for a mixed methods training strategy. *J Strength Cond.* 1994;16:20-31.
54. Newton RU, Kraemer WJ, Hakkinen K. Effects of ballistic training on preseason preparation of elite volleyball players. *Med Sci Sports Exerc.* 1999;31:323-330.
55. Ohberg L, Lorentzon R, Alfredson H. Eccentric training in patients with chronic Achilles tendinosis: normalized tendon structure and decreased thickness at follow-up. *Br J Sports Med.* 2004;38:8-11.
56. Ostrowski KJ, Wilson GJ, Weatherby R, Murphy PW, Lyttle AD. The effect of weight training volume on hormonal output and muscular size and function. *J Strength Cond Res.* 1997;11:148-154.
57. Pearson D, Faigenbaum A, Conley M, Kraemer WJ. The National Strength and Conditioning Association's basic guidelines for the resistance training of athletes. *Strength Cond J.* 2000;22:14-27.
58. Peterson MD, Rhea MR, Alvar BA. Maximizing strength development in athletes: a meta-analysis to determine the dose-response relationship. *J Strength Cond Res.* 2004;18:377-382.
59. Poliquin C. Five steps to increasing the effectiveness of your strength training program. *NSCA J.* 1988;10:34-39.
60. Prestes J, De Lima C, Frollini AB, et al. Comparison of linear and reverse linear periodization effects on maximal strength and body composition. *J Strength Cond Res.* 2009;23:266-274.
61. Radcliffe JC, Farentinos RC. *High Powered Plyometrics.* Champaign, IL: Human Kinetics; 1999.
62. Ratamess NA, Alvar BA, Evetoch TK, et al. ACSM position stand: progression models in resistance training for healthy adults. *Med Sci Sports Exerc.* 2009;41(3):687-708.
63. Reynolds JM, Gordon TJ, Robergs RA. Prediction of one repetition maximum strength from multiple repetition maximum testing and anthropometry. *J Strength Cond Res.* 2006;20:584-592.
64. Rhea MR, Alderman BL. A meta-analysis of periodized versus nonperiodized strength and power training programs. *Res Q Exerc Sport.* 2004;75:413-423.
65. Rhea MR, Alvar BA, Ball SD, Burkett LN. Three sets of weight training superior to 1 set with equal intensity for eliciting strength. *J Strength Cond Res.* 2002;16:525-529.
66. Rhea MR, Alvar BA, Burkett LN, Ball SD. A meta-analysis to determine the dose response for strength development. *Med Sci Sports Exerc.* 2003;35:456-464.
67. Rhea MR, Ball SD, Phillips WT, Burkett LN. A comparison of linear and daily undulating periodized programs with equated volume and intensity for strength. *J Strength Cond Res.* 2002;16:250-255.
68. Rhea MR, Phillips WT, Burkett LN, et al. A comparison of linear and daily undulating programs with equated volume and intensity for local muscular endurance. *J Strength Cond Res.* 2003;17:82-87.
69. Sanborn K, Boros R, Hruby J, et al. Short-term performance effects of weight training with multiple sets not to failure vs a single set to failure in women. *J Strength Cond Res.* 2000;14:328-331.
70. Schiotz MK, Potteiger JA, Huntsinger PG, Denmark DC. The short-term effects of periodized and constant-intensity training on body composition, strength, and performance. *J Strength Cond Res.* 1998;12:173-178.
71. Schlumberger A, Stec J, Schmidtbleicher D. Single- vs multiple-set strength training in women. *J Strength Cond Res.* 2001;15:284-289.
72. Selye H. *Stress Without Distress.* New York, NY: JB Lippincott; 1974.
73. Shalabi A, Kristoffersen-Wilberg M, Svensson L, Aspelin P, Movin T. Eccentric training of the gastrocnemius-soleus complex in chronic Achilles tendinopathy results in decreased tendon volume and intratendinous signal as evaluated by magnetic resonance imaging. *Am J Sports Med.* 2004;32:1286-1296.
74. Siff MC, Verkoshansky YV. *Supertraining.* 4th ed. Denver, CO: Supertraining International; 1999.
75. Starkey DB, Pollock ML, Ishida Y, et al. Effect of resistance training volume on strength and muscle thickness. *Med Sci Sports Exerc.* 1996;28:1311-1320.
76. Stone MH, Johnson RL, Carter DR. A short term comparison of two different methods of resistance training on leg strength and power. *J Athl Train.* 1979;14:158-161.
77. Stone MH, O'Bryant HS. *Weight Training: A Scientific Approach.* Minneapolis, MN: Burgess; 1987.
78. Stone WJ, Coulter SP. Strength/endurance effects from three resistance training protocols with women. *J Strength Cond Res.* 1994;8:231-234.
79. Stowers T, McMillian J, Scala D, et al. The short-term effects of three different strength-power training methods. *NSCA J.* 1983;5:24-27.

80. Thein BL. Endurance impairment. In: Hall CM, Thein BL, eds. *Therapeutic Exercise: Moving Toward Function*, Philadelphia, PA: Lippincott Williams & Wilkins; 1999:87-111.
81. Tran QT, Docherty D, Behm D. The effects of varying time under tension and volume load on acute neuromuscular responses. *Eur J Appl Physiol.* 2006;98:402-410.
82. Wathen D. NSCA position stand: plyometric exercise. *NSCA J.* 1993;15(3):16.
83. Wawryzniak JR, Tracy JE, Catizone PV, Storrow RR. Effect of closed chain exercises on quadriceps femoris peak torque and functional performance. *J Athl Train.* 1996;31:335-340.
84. Weiss LW, Coney HD, Clark FC. Differential functional adaptations to short-term low-, moderate and high-repetition weight training. *J Strength Cond Res.* 1999;13:236-241.
85. Willoughby DS. The effects of mesocycle-length weight training programs involving periodization and partially equated volumes on upper and lower body strength. *J Strength Cond Res.* 1993;7:2-8.
86. Wilson GJ, Murphy AJ, Walshe AD. Performance benefits from weight and plyometric training: effects of initial strength levels. *Coach Sport Sci J.* 1997;2:3-8.
87. Wilson GJ, Newton RU, Murphy AJ, et al. The optimal training load for the development of dynamic athletic performance. *Med Sci Sports Exerc.* 1993;25(11):1279-1286.
88. Witvrouw E, Danneels L, Van Tiggelen D, et al. Open versus closed kinetic chain exercises in patellofemoral pain: a five year prospective randomized study. *Am J Sports Med.* 2004;32:1122-1130.
89. Wong Y, Chan S, Tang K, Ng G. Two modes of weight training programs and patellar stabilization. *J Athl Train.* 2009;44:264-271.
90. Yack HJ, Collins CE, Whieldon TJ. Comparison of closed and open kinetic chain exercise in the anterior cruciate ligament-deficient knee. *Am J Sports Med.* 1993;21:49-53.
91. Zaryski C, Smith DJ. Training principles and issues for ultra-endurance athletes. *Curr Sports Med Rep.* 2005;4:165-170.