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Progressive Resistance Exercise in Physical Therapy: A Summary of Systematic Reviews

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Progressive Resistance Exercise in Physical Therapy: A Summary of Systematic Reviews

Progressive resistance exercise (PRE) is a method of increasing the ability of muscles to generate force. However, the effectiveness and safety of PRE for clients of physical therapists are not well known. The purpose of this article is to review the evidence on positive and negative effects of PRE as a physical therapy intervention. Electronic databases were searched for systematic reviews on PRE and any relevant randomized trials published after the last available review. The search yielded 18 systematic reviews under major areas of physical therapy: cardiopulmonary, musculoskeletal, neuromuscular, and gerontology. Across conditions, PRE was shown to improve the ability to generate force, with moderate to large effect sizes that may carry over into an improved ability to perform daily activities. Further research is needed to determine the potential negative effects of PRE, how to maximize carryover into everyday activities, and what effect, if any, PRE has on societal participation. [Taylor NF, Dodd KJ, Damiano DL. Progressive resistance exercise in physical therapy: a summary of systematic reviews. *Phys Ther.* 2005;85:1208–1223.]

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This perspective examines the potential health benefits of incorporating progressive resistance exercise as a physical therapy intervention.

The principles of progressive resistance exercise (PRE) for increasing force production in muscles have remained virtually unchanged since they were described by DeLorme and Watkins[1] almost 60 years ago. These principles are (1) to perform a small number of repetitions until fatigue, (2) to allow sufficient rest between exercises for recovery, and (3) to increase the resistance as the ability to generate force increases. These principles are detailed in the guidelines of the American College of Sports Medicine (ACSM),[2] where it is recommended that loads corresponding to an 8- to 12-repetition maximum (RM) be lifted in 1 to 3 sets, training 2 or 3 days each week. An 8RM to 12RM load is the amount of weight that can be lifted through the available range of motion 8 to 12 times before needing a rest.

Traditionally, PRE has been used by young adults who are healthy to improve athletic performance. However, recent reviews have emphasized the potential health benefits of including PRE as part of the promotion of physical activity in the community.[3,4] The potential health benefits of incorporating PRE into an overall fitness program include helping to reduce risk factors associated with osteoporosis as well as diseases such as cardiovascular disease and diabetes.

The health benefits associated with PRE also may make it a useful intervention in physical therapy. A reduced ability of muscles to generate force, due to injury, pathology, or disuse, is a common impairment in clients seen by physical therapists. If a lack of force generation by muscles is an impairment contributing to an inability to perform everyday activities, then this provides a rationale for physical therapists to apply the principles of PRE when designing treatment programs.

Despite the prevalence of impairment in the ability to exert adequate muscle force, the extent to which PRE has been used in physical therapy is not well known because of the variable use of the term "strengthening." The term "strengthening" has been criticized because of its vagueness, as it could be misinterpreted as referring to any type of muscle training exercise.[5] To illustrate this possibility, a survey of physical therapy treatment choices for musculoskeletal impairments suggested that the prescription of "strengthening" exercises may be relatively common.[6] It was reported that between 52% and 69% of physical therapy treatments for spinal impairment included "strengthening" exercises and that up to 87% of treatments for knee impairments included "strengthening" exercises.[6] However, a difficulty in interpreting data such as these is the inconsistent use and perhaps overuse of the term "strengthening" and, when used, whether the exercise regimens were consistent with the principles of PRE. Therefore, the extent to which PRE has been used or is appropriate for physical therapy remains unclear.

Concerns have been raised about the possible negative effects and safety of PRE. Traditionally (eg, in the area of neuromuscular physical therapy), there have been concerns that training muscles to increase force production could have a negative effect by increasing muscle spasticity.[7] In musculoskeletal physical therapy, safety concerns have been raised about the application of the relatively high forces required for PRE training through healing tissues, such as through bone after fracture.[8]

The primary aim of this review was to examine the positive and negative effects of PRE as an intervention in physical therapy using evidence from available systematic reviews. Where more than 1 systematic review was available in an area, the quality of the systematic reviews was taken into account in interpreting the findings. The key question to be answered in this review was: What is the evidence that PRE can improve outcomes in people who would be prescribed treatment by a physical therapist? Evidence about the positive or negative outcomes of PRE was described according to the domains of the *International Classification of Functioning, Disability and Health (ICF)*.[9] Using this framework, within the domain of "Body Function and Structure," evidence available about whether PRE could improve the ability to generate muscle force was analyzed. Within the domain of "Activ-

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All authors provided concept/idea/project design, data collection and analysis, writing, and consultation (including review of manuscript before submission). Dr Taylor provided project management.

Table 1.
Inclusion and Exclusion Criteria

	Inclusion	Exclusion
Population	People with an impairment of body structure or function, such as people with muscle force deficit (eg, older people) or people with pathology affecting movement (eg, stroke)	People without an impairment of body structure or function (eg, there is no impairment of muscle force production such as bodybuilding or training people without impairment to improve athletic performance)
Intervention	Progressive resistance exercise (PRE); must conform to guidelines for PRE training, including sufficient intensity (eg, 60%–80% of 1 repetition maximum) and progression of resistance	Other exercise that does not conform to the guidelines of PRE, such as functional strengthening, increasing core stability, or resistance exercise without progression
	Emphasis or major part of the review focuses on progressive resistance exercise	If only a minor part of the review is on PRE (eg, focus of review is on physical therapy modalities that may include exercise)
Study design	Systematic reviews with a documented search strategy, including search terms and databases accessed	Literature reviews without a documented search strategy Opinion reviews from authorities
	The term "systematic review" or "meta-analysis" is mentioned in the title, abstract, or key words or search is strategy documented in abstract	No mention of the term "systematic review" or "meta-analysis" in title, abstract, or key words or documentation of search strategy in abstract
Outcomes	All outcomes considered in terms of impairment, activity limitation, and participation restriction	Correlation-type outcomes
Publications	Articles written in English and published in peer-reviewed journals	Non-English; abstracts, dissertations, book chapters

ities and Participation," evidence about whether the ability to complete everyday tasks or the ability to participate in societal roles had improved was analyzed.

Method

Search Strategy

To identify relevant systematic reviews, electronic databases (DARE, MEDLINE, CINAHL, EMBASE, and the Cochrane controlled trials register and systematic reviews database) were searched back to the earliest time available until June 2004 using the following key words: "resistance," "strength," "weight training," and "progressive resistance exercise." These terms were combined in a search strategy developed by the UK Cochrane Centre to identify systematic reviews and meta-analyses (Appendix).[10] Analysis of sensitivity and precision in another study[11] showed the strategy has 93.6% sensitivity (percentage of systematic reviews correctly classified) and 11.3% precision (percentage of correctly classified systematic reviews relative to the total number of articles retrieved) for detecting relevant articles. This search was supplemented by citation tracking of researchers publishing in relevant areas and scanning the reference lists of relevant reviews. In addition, to ensure that this review included the most current knowledge available, electronic databases were searched to locate any relevant randomized controlled trials (RCTs) that had been published since the last available systematic review in that area of physical therapy.

Two reviewers (NFT and KJD) independently screened the titles and abstracts of articles identified by the initial search strategy for inclusion and exclusion criteria (Tab. 1). The inclusion criteria were designed to identify full articles written in English that fulfilled the key elements of our research question: (1) population—people who had an impaired ability to generate muscle force and who might be expected to consult a physical therapist; (2) intervention—PRE; and (3) study design—only systematic reviews, meta-analyses, or RCTs published since the latest systematic review had been completed, because these types of studies form the highest level of evidence about the effectiveness of an intervention.[12] When the title and abstract did not clearly indicate whether an article should be included, the full article was read and evaluated for inclusion criteria. To be included, articles had to fulfill all criteria.

Data Analysis

The articles identified by the search strategy were classified under the following major areas of physical therapy: cardiopulmonary, musculoskeletal, neuromuscular, and gerontology. Data from the articles were extracted descriptively and included details on the population studied, the research designs utilized, and the number of clinical trials and number of participants on which the review was based. Where available, the standardized effects of PRE in the form of effect sizes were described and interpreted according to Cohen's standards of a small effect ($d=0.20$), a medium effect ($d=0.50$), or a large effect ($d=0.80$).[13]

Quality Items	Yes=2 Points	Partial=1 Point	No=0 Points
1. Were the search methods used to find evidence (primary studies) on the primary question(s) stated?			
2. Was the search for evidence reasonably comprehensive?			
3. Were the criteria used for deciding which studies to include in the review reported?			
4. Was bias in the selection of articles avoided?			
5. Were the criteria used for assessing the validity for the studies that were reviewed reported?			
6. Was the validity for each study cited assessed using appropriate criteria (either in selecting studies for inclusion or in analyzing the studies that are cited)?			
7. Were the methods used to combine the findings for the relevant studies (to reach a conclusion) reported?			
8. Were the findings of the relevant studies combined appropriately relative to the primary question the review addresses?			
9. Were the conclusions made by the author(s) supported by the data or analysis reported in the review?			
Total quality score (maximum 18)			

Figure.
Quality assessment of systematic reviews.[14]

The scientific quality of the included systematic reviews was assessed using Hoving and colleagues'[14] modified version of the reliable and valid checklist reported by Oxman and Guyatt[15] and Oxman et al.[16] Methodological quality was determined independently by 2 assessors, using the sum of scores of 9 items (in search methods, selection methods, validity assessment, and synthesis), with a maximum score of 18, indicating excellent quality (Figure). Each item was scored as 0 ("no"), 1 ("can't tell"), or 2 ("yes"). Any disagreement in scoring between the 2 assessors was resolved by discussion, with a third assessor, if necessary, until consensus was achieved.

Results

Yield

The initial search strategy yielded 1,198 articles. After initial screening for inclusion, 24 potentially relevant systematic reviews or meta-analyses remained. Complete copies of these articles were obtained, and a further 6 articles were excluded because they did not fulfill the inclusion criteria. Two of these articles were excluded because the review focused on blood lipids[17] or intellectual disability,[18] impairments not commonly referred to physical therapists for management. Three reviews were excluded because the focus was not on PRE,[19–21] and 1 review was excluded because it did not use a systematic search strategy.[22] The final list contained 18 systematic reviews: 4 reviews in the area of cardiopulmonary physical therapy,[23–26] 5 reviews in the area of musculoskeletal physical therapy,[27–31] 4 reviews in the area of neuromuscular physical therapy,[32–35] and 5 reviews in the area of gerontological physical therapy.[36–40]

Cardiopulmonary Physical Therapy

The search for systematic reviews on PRE training in the area of cardiopulmonary physical therapy yielded 1 review that evaluated the effect of PRE on people with chronic obstructive pulmonary disease[23] and 3 reviews that evaluated the effect of PRE on blood pressure.[24–26] Summaries of these reviews are shown in Table 2.

Chronic obstructive pulmonary disease. The review on chronic obstructive pulmonary disease received a high quality assessment score (16/18) and included 9 empirical studies with a combined total of 443 participants who had moderate airflow limitation and who were aged a mean of 62 years.[23] Training sessions typically included 6 to 10 exercises using weight machines aimed at increasing muscle force production in the upper limbs, lower limbs, and trunk. Participants generally completed 2 to 4 sets of 6 to 12 repetitions of each exercise at intensities of 50% to 85% of 1RM (the amount of weight that can be lifted through the range of motion just once before fatiguing), training 3 times per week for about 12 weeks. Therefore, the program details were consistent with guidelines for PRE for younger adults,[2] although somewhat more intense than guidelines recommended for older adults.[41]

In terms of impairments, it was concluded in the review[23] that PRE could lead to significant increases in the ability of people with chronic obstructive pulmonary disease to generate muscle force for both the upper body (d=0.70) and lower limbs (d=0.90) with medium to large effect sizes. Consistent with guidelines, PRE appeared to have no effect on respiratory function,[42,43] and its effect on aerobic capacity remains equivocal, with some studies

Table 2.
Systematic Reviews Evaluating the Effects of Progressive Resistance Exercise in Key Areas of Physical Therapy[a]

Authors	Trials Included	Population	No. of Studies	No. of Participants	Quality Assessment	Conclusions: Impairments	Conclusions: Activities/ Participation
Cardiopulmonary							
Halbert et al[24]	RCTs	Normotensive and hypertensive, age range=24–59 y	3	137	14	Nonsignificant change in blood pressure	
Kelley[25]	RCTs and CTs	Normotensive and hypertensive, mean age=40 y	9	259	8	Reduced resting systolic and diastolic blood pressure	
Kelley and Kelley[26]	RCTs	Normotensive and hypertensive, mean age=47 y	11	320	16	Reduced resting systolic and diastolic blood pressure	
O'Shea et al[23]	CTs, pretest-posttest clinical trials and reviews	COPD, mean age=62 y	13	443	16	Increased upper- and lower-limb muscle force production	No effect on walking or cycling endurance
Musculoskeletal							
Hubley-Kozey et al[28]	RCTs and CTs	Chronic low back pain, age range=35–70 y	6	576	11	Increased trunk extensor and flexor force production; reduced pain	Improved activity (disability questionnaires)
Liddle et al[30]	RCTs	Chronic low back pain, age range=18–76 y	12	1,358	16	Increased muscle force production; reduced pain	Improved activity
Murdoch et al[31]	RCT and pretest-posttest clinical trial	Fracture: 2 studies, mean age=79–81 y; 1 study, mean age=35 y	3	118	16	Increased muscle force production	Improved activity (walking, stairs, chair rise)
Sarig-Bahat[29]	RCTs and CTs	Chronic neck pain, age range=20–65 y	4	418	12	Increased muscle force production; increased ROM; reduced pain	Improved activity (disability questionnaires)
van Baar et al[27]	RCTs and systematic reviews	OA of the hip and knee, age >60 y	2	640	14	Reduced pain	Improved walking performance; improved patient global assessment of effect
Neuromuscular							
Darrah et al[32]	1 RCT and 6 pretest-posttest clinical trials or single-case trials	Cerebral palsy, age range=6–26 y	7	74	7	Increased muscle force production; no evidence of negative effects on muscle spasticity	Effect on activity unclear
Dodd et al[33]	1 RCT, 9 pretest-posttest clinical trials and reviews	Cerebral palsy, 9/10 studies: age range=4–20 y; 1 study, age=up to 47 y	11	126	16	Increased muscle force production; ROM not less and perhaps better; spasticity not worse and may improve	Improved WC propulsion; may improve in dimensions D and E of the Gross Motor Function Measure; walking speed increase inconclusive

(continued)

Table 2.
Continued

Authors	Trials Included	Population	No. of Studies	No. of Participants	Quality Assessment	Conclusions: Impairments	Conclusions: Activities/ Participation
Morris et al[34]	RCTs, pretest-posttest clinical trials, single-case trials	Stroke, mean age range=45.5–70 y, time since stroke=4 wk to 33 y	8	201	17	Increased muscle force production No evidence of negative effects on spasticity or flexibility No change in depression	Equivocal effects on activity, with some studies showing improvements in standing, walking speed, stair climbing, and arm function, whereas other studies showed no effect
Saunders et al[35]	RCTs	Stroke, age range=56–61 y, time since stroke=<3 mo to 3.3 y	2	97	17	Inconclusive effect on ability to increase muscle force production	Inconclusive effect on activity
Gerontology							
Boulé et al[38]	RCTs and CTs	Type 2 diabetes, mean age=51 and 65 y	2	59	17	No effect on fat mass, mixed effects on glycemic control	None
Kelley et al[39]	RCTs and CTs	Women aged >18 y	16 (older women)	577 (older women)	16	No change in BMD in proximal femur; small, but significant, effect at lumbar spine and radius; women who were postmenopausal showed greater effect than younger women	None
Latham et al[40]	RCTs	People aged >60 y, including those with medical conditions and "frail" older people	62	3,674	16	Increased leg extensor muscle force production; no clear effect on aerobic capacity	Speed of moving from sitting to standing position improved; unclear effect on walking speed; no change in standing balance
Toth et al[36]	RCTs, CTs, and pretest-posttest trials	People aged >55 y	28	536	6	Increased fat-free mass; reduced percentage of body fat mass	None
Wolff et al[37]	RCTs and CTs	Women, mean age range=19.9–79 y	6	192	12	No change in lumbar or femoral neck BMD	None

[a] RCT=randomized controlled trial, CT=controlled trial, BMD=bone mineral density, OA=osteoarthritis, COPD=chronic obstructive pulmonary disease, ROM=range of motion, WC=wheelchair. Quality assessment scored out of 18, with higher scores indicating higher quality.

demonstrating improvement[44,45] and others demonstrating no effect.[46,47] Progressive resistance exercise protocols, in isolation, may not provide a sufficient physiological stimulus to cause changes in cardiorespiratory fitness.[41]

Most studies investigated activity by measuring changes in walking endurance (such as during a 6-minute walk test or a shuttle walk test) or cycling endurance and, in most cases, demonstrated nonsignificant effects. It could be argued that measures of walking and cycling endurance may not adequately reflect activity limitation or walking abilities in daily life. In contrast, when a more generalized measure of activity, the physical function domain of the Medical Outcomes Study 36-Item Short-Form Health Survey questionnaire (SF-36), was used, a large positive effect (d=1.64) for PRE was found.[48] The range of activities measured in studies investigating the effect of PRE on people with chronic obstructive pulmonary disease to date has been limited, and the use of scales investigating activities such as dynamic balance, self-care, and upper-limb activity limitation may be more relevant and warranted in future studies. The effect of PRE on the ability of people with chronic obstructive pulmonary disease to participate in their normal societal roles also is largely unknown. One study showed a large positive effect (d=1.41) on the societal function domain of the SF-36.[48] However, another study demonstrated no effect for societal participation after PRE, as assessed with the St George Respiratory Questionnaire. This questionnaire includes items relating to the impact of chronic obstructive pulmonary disease on daily life, such as the ability to work.[49]

Progressive resistance exercise programs appear to be safe for people with chronic obstructive pulmonary disease. No studies showed any adverse events, and reasons for participant withdrawal were factors such as hospitalization, lack of motivation, and injury unrelated to training. However, in interpreting the apparent safety of PRE for people with chronic obstructive pulmonary disease, it should be remembered that most studies excluded people with comorbidities such as cardiovascular disease and pulmonary hypertension. Careful consideration, therefore, should be given when prescribing PRE for people with chronic obstructive pulmonary disease where comorbidities exist. Two of the 9 studies included in the systematic review included a follow-up assessment, with the positive effect sizes maintained at 12 weeks[50] and 12 months[51] after completion of the PRE program.

Blood pressure. Three reviews evaluated the effect of PRE on blood pressure.[24–26] Hypertension is a major health problem[52] and is relevant to physical therapy because relatively small reductions in blood pressure can result in decreased risk for stroke and myocardial infarction.[53] The review by Kelley[25] was based on 9 empirical studies (259 participants), and the review by Kelley and Kelley[26] was based on 11 empirical studies (320 participants). The main difference between the 2 reviews was that the review by Kelley and Kelley[26] was solely based on RCTs and received a high quality assessment score (16/18), whereas the review by Kelley[25] also included nonrandomized trials with a much lower quality assessment score (8/18); these 2 reviews included 4 studies in common. The review by Halbert et al[24] included only 3 RCTs, all of which were included in the other 2 reviews, and so will not be discussed further.

Participants in the trials included in the 2 remaining reviews,[25,26] on average, were aged in their forties and, in most cases, were not hypertensive. Participants typically completed 10 exercises for the arms and legs on weight machines. Participants completed, on average, 2 sets of 5 to 15 repetitions of each exercise, with a training intensity ranging from 30% to 90% of 1RM. Participants typically trained 3 times per week for 14 weeks.

Meta-analyses demonstrated small, but significant, reductions in both systolic and diastolic blood pressures after PRE.[25,26] The magnitude of the reductions ranged from 3.0 to 4.6 mm Hg for systolic blood pressure and from 3.0 to 3.8 mm Hg for diastolic blood pressure, with the smaller values reported from the systematic review based on RCTs.[26] An RCT conducted since the last available systematic review investigated 62 older adults who were healthy and who were randomly assigned to a control group, a low-intensity PRE exercise group, or a high-intensity PRE exercise group.[45] The high-intensity PRE exercise group completed 1 set of 8 repetitions of 13 exercises for arms and legs on weight machines, exercising at an intensity of 80% of 1RM 3 times per week for 24 weeks. Consistent with the systematic reviews, the RCT found positive blood pressure responses to PRE in the high-intensity exercise group, with diastolic blood pressure, mean arterial pressure, and heart rate all being significantly reduced.

None of the 3 systematic reviews investigated adverse events. However, the recent RCT by Vincent et al[45] showed that 6 of the participants in the PRE group experienced joint discomfort that led to a reduction in training for 2 weeks. In 1 systematic review,[26] an average of 18% of participants in the PRE group dropped out before study completion, although the reasons for dropping out were not reported. None of the systematic reviews indicated whether any blood pressure benefits were maintained after the intervention. Because most studies to date have been completed on people without high blood pressure, further studies on participants with hypertension are warranted before recommendations can be made on the safety and usefulness of PRE as an intervention. Systematic reviews on the role of PRE in other areas of physical therapy, such as for people enrolled in cardiac rehabilitation, for recipients of heart transplant, and for people with chronic heart failure, were not located.

Musculoskeletal Physical Therapy

Three reviews in the area of musculoskeletal physical therapy evaluated the effect of resistance training on chronic spinal pain,[28–30] 1 review evaluated the effect of PRE on people after bony fractures,[31] and 1 review evaluated people with osteoarthritis.[27] Summaries of these 5 systematic reviews are shown in Table 2.

Chronic neck and back pain. The 2 systematic reviews on the effect of PRE for chronic low back pain were based on 6 (N=576)[28] and 12 (N=1,358)[30] controlled trials, respectively. The 2 reviews on back pain scored moderate to high on quality assessment (11/18,[28] 16/18[30]) and had 3 trials in common. The systematic review on chronic neck pain[29] was based on 4 controlled trials (N=418), and it scored moderately (12/18) on quality assessment. Typically, participants in both low back pain and neck pain reviews were aged between 40 and 60 years, reflecting the expected typical age distribution of people with chronic spinal pain.

A representative training program involved participants performing 1 to 4 exercises aimed specifically at the muscles of the cervical or lumbar spine. A variety of equipment was used to provide resistance, including body weight, machine weights, or free weights. There was also variety in training parameters, with participants completing 1 to 3 sets of 8 to 12 repetitions[54] or 15 to 20 repetitions[55,56] of each exercise before fatigue (ie, training intensity of 8RM–12RM or 15RM–20RM). Participants typically trained 2 or 3 times per week for approximately 10 to 12 weeks.[54–56] The training intensity of 15RM to 20RM[55,56] is more consistent with recommended guidelines for increasing muscular endurance rather than for increasing the ability of muscle to generate maximal force.[2]

Interpretation of the results of the 3 systematic reviews on spinal pain was difficult because it was not always clear whether the exercise programs were consistent with PRE principles. First, resistance training was defined loosely. Even when the ACSM guidelines for PRE were used as an inclusion criterion for a systematic review,[30] some studies that did not conform to these guidelines were included (eg, O'Sullivan et al[57]). Second, a number of the original articles on which the 3 systematic reviews were based did not report sufficient details for the reader to judge whether training conformed to the principles of PRE (eg, Kankaanpaa et al,[58] Mannion et al[59]). It seems there is still much confusion in the physical therapy and rehabilitation literature over the term "strengthening exercises," with many researchers interpreting it to mean any exercises involving any form of resistance or muscle training.

The reviews on low back pain and neck pain each concluded that resistance training led to reduced pain and an increased ability to generate muscle force. There also was evidence that the increased ability to generate muscle force was accompanied by hypertrophy of the trunk muscles.[56] Progressive resistance exercise led to improved activity in people with chronic spinal pain, as evaluated with disability questionnaires such as the Roland-Morris Disability Scale. The small number of trials (n=5) that evaluated societal participation did not demonstrate any difference in work disability between PRE and control groups.[30]

Another finding was that PRE was more effective than no intervention, but that when compared with other exercise protocols, such as flexibility and aerobic training, all exercise groups improved in a similar manner.[29,30] People with chronic spinal pain often are deconditioned,[60] with impaired muscle performance,[61] providing a rationale for interventions such as PRE. However, the systematic reviews on chronic spinal pain suggest that adherence to an exercise program may provide the main stimulus for functional recovery.[62] The specific type of exercise that led to these improvements may be less important.

It remains unclear whether the benefits of PRE are maintained after training stops, with 1 review[30] concluding that positive results were maintained at more than 9 months, whereas another review[28] concluded that the muscle endurance gains were retained at 6 months but had returned to baseline values by the 12-month follow-up.

Only 1 of the 3 reviews evaluated whether adverse effects occurred as a result of PRE. In that review,[30] the authors found the evidence insufficient to make a conclusion, because adverse events were often not reported to have been monitored in the reviewed trials.

Arthritis. One systematic review[27] that focused on the effect of exercise therapy in people with hip and knee osteoarthritis was found. This review (quality score of 14/18) was based on 2 RCTs[63,64] with a large number of participants (N=640) (Tab. 2). The training program was consistent with PRE principles. Participants completed 2 sets of 12 repetitions of 9 exercises for upper and lower limbs, with resistance increased after a participant could complete 2 sets of 12 repetitions for 3 consecutive days (considered a training intensity of 12RM). Resistance was provided with dumbbells and cuff weights. Exercises were performed 3 times per week for 18 months, with the first 3 months as group training in a facility and the last 15 months as a home-based program.[63]

The systematic review[27] concluded that a PRE program reduced pain and improved activity, as represented by a timed 6-minute walk and self-reported disability in areas such as transferring. Effect sizes were small to moderate, ranging from d=0.26 for self-reported disability to d=0.58 for pain. An RCT[65] published since the most recent systematic review supported the findings of the included systematic review.

The authors of the systematic review[27] did not report on adverse events. However, Ettinger et al[63] reported that, of the 146 people assigned to a PRE group, 2 people fell during training and 1 person dropped a dumbbell on her foot, resulting in a fracture. The included studies did not include a follow-up assessment, so it is not known whether the positive effects were maintained after training stopped.

Fractures. One high-quality systematic review[31] (quality score of 16/18) that investigated the effect of PRE on the rehabilitation of people after bony fracture was located (Tab. 2). Relatively little information is available in this area, with only 3 studies,[66–68] which had a small number of participants (N=118), being included in the systematic review. Two studies[66,67] investigated older people (average age=79–81 years) after fracture of the neck of the femur, and 1 study[68] investigated a younger group of people (mean age=35 years) after ankle fracture. The typical program comprised 1 to 5 exercises aimed at increasing muscle force production of the lower limbs, using weight machines, body weight, or weighted sandbags for resistance. Participants generally completed 2 or 3 sets of 8 to 12 repetitions of each exercise at an intensity of 50% to 90% of 1RM. Participants trained 2 or 3 times per week for 6 to 12 weeks. The authors of the review[31] concluded that PRE after fracture resulted in an improved ability to generate muscle force (with effect sizes ranging from d=0.78 to d=5.06) that carried over into improved functional activities, such as walking speed, going up and down stairs, and rising from a chair (range: d=1.36 to d=2.40). The 2 studies[66,67] that included a follow-up period showed that the benefits had mostly dissipated 12 weeks after the end of the program.

No training-related injuries were reported apart from minor problems, such as aching muscles.[67] This finding was noteworthy given safety concerns about applying the relatively high forces associated with PRE through a recent bony fracture[8]; 1 study[66] started training participants within 16 days after surgical fixation of the fractured neck of the femur.

Neuromuscular Physical Therapy

The search strategy yielded 4 systematic reviews in the area of neuromuscular conditions: 2 in cerebral palsy[32,33] and 2 in stroke rehabilitation.[34,35] Summaries of the 4 reviews are shown in Table 2.

Cerebral palsy. The typical PRE program for people with cerebral palsy comprised 2 to 4 exercises using isokinetic dynamometers, weight machines, or free weights. Participants typically completed 3 or 4 sets of 5 to 10 repetitions of each exercise with a training intensity of 50% to 65% of 1RM. Participants usually trained 3 times per week for periods ranging from 6 to 10 weeks. The studies were quite diverse in the types of participants enrolled and included children and adults aged from 4 to 47 years with spastic hemiplegia, diplegia, or quadriplegia alone or in combination, as well as a small number of people with ataxia or dystonia.

The effect that PRE can have on body structure and function has received the most attention. One high-quality systematic review[33] (quality score of 16/18) of 10 studies (9 single-group pretest-posttest studies and 1 RCT) with a total of 126 participants (106 participants in the experimental group) concluded that there is strong evidence supporting the view that PRE can increase the ability to generate muscle force in people with cerebral palsy, with effect sizes from individual trials ranging from d=0.24 to d=5.27. This conclusion was supported by another systematic review[32] of 7 studies (6 single-group pretest-posttest studies and 1 RCT), 4 of which were included in the review by Dodd et al.[33]

Traditionally, clinical concern has been expressed that the exercise intensity required during PRE would increase hypertonia in people classified as having spastic cerebral palsy (spasticity here being operationally defined as an increased resistance to passive movement) and that this might lead to reduced joint range of movement and stiffness, making it even more difficult for these people to move. This concern has been investigated in only 1 review[33] that concluded, based on 2 single-group pretest-posttest trials,[69,70] that participation in a PRE program did not have a detrimental effect on hypertonia. Similarly, the same review concluded, based on 4 single-group pretest-posttest trials[69–72] that investigated the effect of PRE on range of movement, that PRE did not lead to a loss of range of movement. Three of the trials showed significant increases in range of movement after completion of a PRE program.[33]

Few studies have been conducted on the effects of PRE on activities and societal participation in people with cerebral palsy. However, preliminary evidence suggests that PRE might have a small to moderate effect on activity limitations. Individual trials have shown improvements in the Gross Motor Function Measure dimensions D (standing items)[69] and E (walking, running, and jumping items)[69,73] after participation in a PRE program targeting the lower limbs. One trial[73] also showed improvements in self-selected walking speed, but another trial[69] showed no increase in self-selected or fast walking speeds. The conflicting results from the 2 studies that investigated walking speed[69,73] could perhaps be attributed to the fact that the exercise program was individually designed in 1 trial,[73] whereas a fixed protocol was used in the other trial.[69] The effects of PRE on societal participation were not formally measured in any of the trials. However, it was noted anecdotally that some participants in 2 studies[74,75] developed the confidence to join community exercise programs after study completion.

Since the 2 systematic reviews were published, a further 2 relevant RCTs have been published. One RCT[76] recruited 21 children aged 8 to 18 years with spastic diplegic cerebral palsy, 11 of whom underwent a 6-week home-based PRE program targeting the muscles of the lower limbs. The results of this study reinforced previous findings of an increase in the ability to generate muscle force after completing a PRE program.[32,33] However, this study showed only a positive trend toward improved activity after PRE training compared with nonexercising controls. The other RCT[77] recruited 17 adults aged 23 to 44 years with spastic diplegic cerebral palsy, 10 of whom completed a 10-week PRE program targeting the muscles of the lower limbs. In contrast to most other trials, the results of the trial by Andersson et al[77] did not show a significant difference between the PRE and nonexercising control groups in the ability to generate muscle force. Furthermore, no significant differences between the groups were detected for changes in dimensions D and E of the Gross Motor Function Measure, for distance walked in the 6-minute walking test, and for speed of the Timed "Up & Go" Test.

The ability of people with cerebral palsy to have time off from training and maintain some of the gains achieved generally remains unknown because few trials have included a follow-up period of testing after completion of the program. However, one recent RCT[76] showed that the improved ability to generate muscle force was maintained for a period of 3 months after completion of the program.

For only 2 trials[73,76] were adverse events from training explicitly reported. Three participants from the cohort of 11 participants in 1 trial[76] reported minor discomfort. A simple modification to the exercise enabled these participants to continue without further incident. The other trial[73] that recorded adverse events showed that, from a cohort of 11 children with cerebral palsy, only a few transient complaints of mild muscle soreness occurred.

Stroke. The typical training program for people with stroke comprised 4 to 8 exercises using isokinetic dynamometers, weight machines, or free weights. Participants typically completed 1 to 3 sets of 6 to 10 repetitions of each exercise with a training intensity of 10RM (the maximal load that a participant can lift 10 times with good form before needing to rest). Participants usually trained from 2 to 5 times per week for periods ranging from 4 to 12 weeks. Each program was tailored to the individual patient's needs, and all programs were conducted under one-to-one supervision.

One systematic review,[34] which had a high-quality score (17/18), identified 8 studies in the stroke literature, 3 of which were RCTs utilizing PRE in isolation. Another included systematic review,[35] although rated highly for quality (17/18), was based on 2 studies, 1 of which was included in the review by Morris et al.[34] The review by Morris et al included 201 patients with mean ages ranging from 45.5 to 70 years. This review showed consistent and significant gains in the ability to generate muscle force, with large effect sizes ranging from $d=1.2$ to $d=4.5$. Improvements in activity across studies were less dramatic and inconsistent. One RCT[78] showed a large effect size for improvement in self-selected walking speed in the PRE group, with no significant gains in upper-limb functional activities even though both hemiplegic limbs were trained. In contrast, the only other trial on upper-limb training[79] indicated that 26 of the 27 participants improved in upper-limb functional tasks. Although several studies included measures or components of measures that evaluated aspects of societal participation, no separate analyses were done on these data in any of the trials, so the effects on societal participation remain unknown.

Only 1 trial[80] in the review by Morris et al[34] demonstrated adverse events, with 1 of 7 participants reporting minor back pain and 1 participant reporting knee pain on the nonhemiplegic side. No need for analgesia or missed sessions due to discomfort were reported in any of the trials, nor were any adverse cardiopulmonary events noted.

The other systematic review located examined the effects of various types of physical fitness training for people with stroke.[35] The effects of 2 RCTs that included only PRE were reported.[35] One of these trials[81] was not included in the review by Morris et al.[34] In that trial, 20 patients were randomly assigned to an isokinetic training program for 6 lower-limb muscles for 6 weeks compared with a group that received range-of-motion exercises only. Summed percentage of change in muscle force production was more than 3 times greater in the isokinetic training group, although the difference did not reach significance ($P>.06$). Self-selected walking speed changed marginally in both groups, with no significant differences between groups. Likewise, no group differences were seen as a result of the program on physical or mental health aspects measured. The review concluded that insufficient data were available to determine whether the ability of muscle to generate force can be increased through training or whether functional benefits would result from PRE in patients after stroke.

Two recent RCTs[82,83] that were published after the 2 reviews[34,35] generally support the view that PRE can increase the ability to generate muscle force in people with stroke. However, these trials have added to the ambiguity with respect to improvements in activity after PRE training. In a study of 141 patients who were randomly assigned to an exercise program with or without PRE,[82] no benefits of activity were noted for the resistance training group. The authors suggested that the lack of a difference could have been due to increased fatigue in the more intensely trained group. Adverse events were monitored very closely in this trial, with pain and stiffness being the most prevalent complaints. Although the number of events tended to be larger in the experimental group, the differences between groups were not significant, no one withdrew from the trial because of them, and none were noted at the end of the trial. In the other recently published RCT,[83] 42 people with stroke were randomly assigned to either a 12-week stretching group or a group that received PRE of the lower limbs. The authors reported positive outcomes in the ability to generate muscle force and self-reported function in the PRE group only.

In summary, PRE has been safely utilized in patients with central nervous system injuries, with beneficial effects on the ability to generate muscle force usually being noted and improvements in functional activities being demonstrated in some, but not all, cases. The efficacy of specific exercise programs for clearly defined patient groups in producing substantial functional benefits and the role of PRE in the enhancement of societal participation, particularly by those programs conducted in group or community-based settings, still need to be determined.

Gerontological Physical Therapy

The search for articles on the effects of PRE in the area of gerontological physical therapy yielded 5 reviews. One of these reviews[40] evaluated the effect of PRE on a range of physical disability outcome measures, including changes in body structure and function (eg, ability to generate muscle force) and changes in functional activities (eg, walking speed) for a mixed group of older people who were healthy and older people with health problems or functional limitations. Another review[36] focused specifically on the effects of PRE on body composition in people aged over 55 years. Two reviews[37,39] specifically evaluated the effect of PRE on bone mineral density (BMD), with a majority of the trials including samples of older people. One review[38] evaluated the effect of PRE on older people with type 2 diabetes. Summaries of the 5 reviews are presented in Table 2.

The typical training program for older people comprised 8 to 10 exercises using weight machines aimed at increasing muscle force production in the upper limbs, lower limbs, and trunk. Participants generally completed 2 or 3 sets of 6 to 12 repetitions of each exercise with a training intensity of 70% to 80% of 1RM. Participants typically trained 2 or 3 times per week for periods ranging from 6 weeks to 2 years. The program content was similar to guidelines for PRE training recommended by the ACSM for young adults who are healthy.[2] However, the amount and intensity of training were generally greater than the single set of 10 to 15 repetitions to fatigue of each exercise recommended by the ACSM for older adults.[41]

The effect that PRE can have on body structure and function has been the subject of most attention. Strong evidence is available supporting the view that PRE can increase the ability to generate muscle force in older people.[40] Some evidence also exists showing that PRE can lead to an increase in fat-free mass in older people, with a significant portion of fat-free mass being caused by an increase in skeletal muscle mass.[36]

The effect of PRE on BMD in older people was investigated in 2 reviews of moderate to high quality, but the findings remain equivocal. Typically, programs designed to improve BMD were longer in duration than programs designed to increase the ability to generate muscle force or improve activities such as walking. The duration of programs designed to improve BMD ranged from 24 to 208 weeks, and mostly they investigated the effects of PRE on women rather than men. One meta-analysis[37] concluded that PRE had no significant effect on increasing lumbar spine BMD or femoral neck BMD in older people, based on the pooled results of 6 trials (all RCTs) that included 192 experimental participants and 114 participants who acted as controls. In contrast, a separate meta-analysis[39] of 16 trials (11 RCTs, 5 controlled trials) (including 5 of the 6 trials in the other review[37]), based on 276 participants who completed a PRE program and 279 participants who served as nonexercising controls, showed a small, but significant, effect of resistance training for maintaining lumbar spine BMD in women who were postmenopausal. One of the limitations of this literature is that relatively few trials have investigated the effects of PRE on BMD in isolation, and it is possible that larger RCTs may yet demonstrate that PRE has some beneficial effects on bone health. Currently, however, PRE appears to have a relatively small effect on bone health compared with weight-bearing aerobic training.

One high-quality systematic review[38] (quality score of 17/18) that examined the effect of PRE on glycemic control (reduction of hyperglycemia) and body mass in people with type 2 diabetes was found. That review highlighted the relatively small number of well-controlled trials that have examined the effects of PRE on people with type 2 diabetes, with the inclusion of only 1 RCT and 1 clinical controlled trial that evaluated the effect of PRE alone. The RCT,[84] which was conducted over 8 weeks, had a sample of 21 participants (11 in the PRE group) with a mean age of 50.7 years. The clinical controlled trial,[85] which was conducted over 22 weeks, had a sample of 38 participants (18 in the PRE group) with a mean age of 64.7 years. In both cases, a circuit-based PRE program targeting the major muscles of the trunk and the upper and lower limbs was developed. Exercises were performed in 2 or 3 sets of 10 to 20 repetitions, 2 or 3 times each week. The meta-analyses failed to detect a significant effect for PRE on glycemic control or fat mass in people with type 2 diabetes. However, strong trends were found for improved glycemic control after participation in a PRE program. A more recent RCT[86] that examined the effect of a high-intensity 6-month circuit-based PRE program on glycemic control in a group of 36 men and women who were overweight, had type 2 diabetes (19 in the PRE group), and were aged between 60 and 80 years supported the view that PRE can significantly reduce hyperglycemia in these people.

Few trials have been conducted on the effects of PRE on activities and societal participation in older people. However, preliminary evidence suggests that PRE may have a small to moderate carryover effect on activities for older people. There is evidence that PRE may lead to increased walking speed in older people, with a meta-analysis indicating a weighted mean difference of 0.07 m/s in favor of those doing PRE.[40] Similarly, a meta-analysis of 4 trials that included a mixed group of older people, including institutionalized and frail older people, demonstrated that PRE had a medium to large effect on the speed of rising from a chair ($d=0.67$).[40] No clear effect was found for PRE on measures of standing balance.[40]

The effects of PRE on the ability to perform roles expected of individuals within their society, such as working or participating in leisure activities (ie, participation restrictions), remain largely unknown because few studies have included outcome measures that have adequately measured this domain of disability in older people. Latham et al,[40] in a meta-analysis of 14 trials, found no effect of PRE on societal participation restrictions in their mixed sample of older people who were healthy and frail. It seems that, although PRE can improve the ability to generate muscle force and might improve the ability to perform some important functional activities, no clear evidence has shown that PRE readily carries over into better societal participation for older adults.

The ability for older people to have time off from training and maintain any benefits gained remains unknown. As shown in other groups, few training-related injuries were reported apart from minor problems such as aching muscles. No cardiac events or deaths attributable to PRE were reported. However, adverse events were not well defined or reported; thus, it is possible that the incidence of adverse events due to PRE is higher than the available literature suggests. For clinicians, this means that older people participating in PRE programs should be carefully monitored for adverse events.

Discussion

Is PRE Effective in Reducing Impairment?

Progressive resistance exercise generally works across conditions to improve the ability of muscle to produce force, and effect sizes, depending on the population studied and the type of program, can vary from modest to rather large. It appears that the muscle response to PRE for people who have a broad range of conditions and who might consult a physical therapist is similar to responses reported in young people without impairment. Variability in muscle responses may be more related to variability in training intensity and adherence than to the specific pathology. Progressive resistance exercise can have a beneficial effect in populations where pain is a particular problem, such as people with low back pain and people with osteoarthritis. In addition, PRE can have a beneficial effect on blood pressure, although few studies have been conducted on participants with hypertension. The effect of PRE on other impairment parameters, such as BMD, fat mass, and aerobic capacity, remains inconclusive.

Is PRE Effective in Improving Activity?

There is evidence that improvements in the ability to generate muscle force can carry over into an improved ability to do everyday tasks. However, the effects are generally more modest, and there are quite a number of examples in the literature where significant improvements in activity were not demonstrated after PRE. The principle of specificity of training and consideration of the specific activity limitations of clients may help to explain these results. According to the principle of specificity of training, improvements are specific to the manner in which training is completed so that one would not necessarily expect improvements in the ability to generate muscle force in the training setting to translate to an improved ability to perform everyday activities.[2] A goal of therapy may be to improve muscle power or muscle endurance, because it is thought that these aspects of muscle performance might relate better to the performance of everyday activities. However, there is evidence that PRE programs that lead to improvements in the ability to increase force production also lead to improvements in muscle power and endurance.[87,88]

Is PRE Effective in Enhancing Societal Participation?

This dimension has received only cursory mention in the literature on PRE and warrants much further study. It cannot necessarily be assumed that increasing the ability of muscles to generate force alone should increase societal participation. The effect may be dependent on the context in which the exercise is performed (eg, a community-based group program may enhance societal participation more than a one-to-one therapy session or home program). The development of better measures of societal participation should greatly facilitate studies in this area.

Is PRE Safe?

Progressive resistance exercise appears to have been applied with safety across many disorders of relevance to physical therapy. Our Perspective article has shown that transient muscle soreness has been reported frequently, which is not unexpected after intense activity. No increases in hypertonia or stiffness have been detected in patients with neuromuscular disorders, although range of motion may be improved.[33,34] No subsequent fractures in patients who have had recent surgical fixation of a fracture have been reported.[31] It seems that there is little evidence to support authoritative recommendations that PRE may be inappropriate in some of the client groups commonly managed by physical therapists. It must be noted here that clinical trials are likely to exclude patients with significant comorbidities, so caution is advised when extrapolating these results to all patients.

There may be other groups not investigated in this Perspective article where particular caution is required before PRE is prescribed. For example, for progressive neuromuscular diseases, such as Duchenne muscular dystrophy, some rationale for not prescribing PRE exists because of concerns that this form of exercise may accelerate muscle fiber damage.[89,90] However, there is little empirical evidence to support this recommendation.

Can PRE Lead to Long-Term Benefits?

The evidence on whether PRE can lead to long-term improvements in impairments and activities that, in turn, can lead to long-term health benefits is inconclusive. In some areas of physical therapy, such as in fracture rehabilitation, the positive effects appear to dissipate after the PRE program stops,[31] whereas in other areas, such as in pulmonary rehabilitation, there is preliminary evidence that participants may maintain benefits to an extent.[23]

It seems likely that patients with chronic disabilities are likely to need regular exercise programs to sustain or augment any benefits achieved in a short-term program. A 9-month trial in patients with spinal cord injuries indicated substantial health benefits with encouraging compliance rates.[91] Long-term programs may prove to be far less costly in health care dollars and more beneficial in terms of health-related quality of life than a more complacent acceptance of secondary complications and a strategy of remedial treatment as these arise. Consistent with this view, for sustained benefits, PRE should be seen as something that is incorporated into an active lifestyle, rather than as a specific therapeutic intervention.

How Can Research Be Improved and Fostered in These Areas?

Progressive resistance exercise needs to be well defined and implemented across studies to foster true evaluations of the potential treatment effects. So as not to do harm to patients, clinicians and researchers unwittingly may be "under-dosing" the amount of resistance and thereby reducing its potential effectiveness. This can easily be remedied by ensuring that fatigue is reached after a small number of repetitions or by measuring the maximum force of the muscle and applying a load that is a relatively high percentage of that value, typically more than 70% or 80% of this value. If clinicians are concerned about initiating a training regimen starting with high-intensity loads, then it is possible to start training at a lower intensity (eg, 50% of 1RM for 1–2 weeks) before increasing training intensity to a more optimal load and still gain successful outcomes.[66] In addition, studies of longer duration are clearly needed, because reaping the benefits of PRE takes time, not just for the muscle itself to respond but for the person to integrate the new capability into his or her movement repertoire.

If PRE alone is shown to be efficacious compared with no treatment, it must then be compared with the other effective treatment strategies aimed at improving the same type of disabilities. Some preliminary evidence in this review in the area of rehabilitation of chronic back pain suggests that PRE might not be more beneficial than other forms of exercise and that the benefit might accrue from adherence to an active form of treatment rather than from the specific stimulus of PRE.[30] Additionally, PRE could be compared with PRE combined with other interventions that have known effects to determine whether this can provide additional benefits.[92]

There is little evidence in the systematic reviews included in this Perspective article about the dose-response needed to maintain force gains after a relatively short PRE program ends. It might be possible that less frequent exercise bouts per week could maintain force gains, which would be easier to sustain as part of a lifestyle change. This may be an important area for future research.

Limitations

One possible limitation of this summary of systematic reviews was that no systematic reviews were excluded on the basis of a low quality assessment score. The quality assessment score was low in several cases, but these reviews were included to ensure that the breadth of available information was sampled. In addition, the quality assessment score was used to provide more information to assist in interpretation of the information presented. A second limitation is that the inclusion criterion for population was designed to include people who had an impaired ability to generate muscle force and who might be expected to consult a physical therapist. Although this strategy appeared to capture the main populations of people who had an impaired ability to generate muscle force and who would consult a physical therapist, there may be other populations in areas that physical therapists work, such as in oncology and women's health, who were not captured by this approach.

Conclusion

Progressive resistance exercise appears to be a safe and efficacious intervention for many patients with muscle force deficits contributing to their motor disability in physical therapy. Despite being able to improve the ability to increase muscle force production, more evidence is needed to determine whether PRE can make substantial or sustained improvements in daily activity or have an effect on societal participation. Progressive resistance exercise for people in more acute phases of recovery or for those with degenerative diseases requires more careful consideration and study but may have positive effects. Due to confusion over the term "strengthening," it is important that researchers and clinicians operationally define the aim and clearly describe their program. It is suggested here that the term "progressive resistance exercise" be used in place of the term "strengthening" or as an added modifier to describe exercise programs that are designed to increase muscle force production and that follow the principles of (1) performing a small number of repetitions (8–12) until fatigue, (2) allowing sufficient rest between exercises for recovery, and (3) increasing the resistance as the ability to generate muscle force develops.

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Appendix.
Search Strategy for MEDLINE Database (OVID Interface)

1. meta-analysis/
2. review literature/
3. meta-analy$.tw
4. metaanal$.tw
5. (systematic$ adj4 (review$ or overview$)).mp
6. meta-analysis.pt
7. review.pt
8. review.ti
9. review literature.pt
10. or/1-9
11. case report/
12. letter.pt
13. historical article.pt
14. review of reported cases.pt
15. review,multicase.pt
16. or/11-15
17. strengthening.ti,ab
18. strength exercise.ti,ab
19. strength training.ti,ab
20. weight training.ti,ab
21. weight lifting.ti,ab
22. resistance training.ti,ab
23. resistance exercise.ti,ab
24. progressive resistance exercise.ti,ab
25. progressive resistance training.ti,ab
26. or/17-25
27. 10 not 16
28. 27 and 26
29. limit 28 to (human and English language)

Physical Therapy
Journal of the American Physical Therapy Association

Progressive Resistance Exercise in Physical Therapy: A Summary of Systematic Reviews
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