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Dysphagia

Review

Strength-Training Exercise in Dysphagia Rehabilitation: Principles, Procedures, and Directions for Future Research

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Abstract. Dysphagia rehabilitation, historically, has focused a great deal on various compensations during swallowing to prevent aspiration and/or improve safety and efficiency. Exercise, in general, has been a part of the dysphagia rehabilitation landscape. However, heightened discussions in the field regarding best practices for exercise training, particularly strengthening, raise more questions than answers. The intent of this paper is to (1) explore the overriding principles of neuromuscular plasticity with regard to strength training, (2) evaluate how current exercise-training interventions in dysphagia rehabilitation correspond to these principles, and (3) postulate directions for future study of normal and disordered swallowing and determine how to incorporate these principles into dysphagia rehabilitation.

Key words: Deglutition — Deglutition disorders — Dysphagia — Swallowing — Exercise — Strengthening — Muscle.

Dysphagia is a pervasive and potentially life-threatening condition that can emerge from a variety of disturbances affecting neural, motor, and/or sensory systems that underlie swallowing function. Published reports indicate a high incidence and prevalence of dysphagia among neurologically impaired individuals [1–4], those with head and neck cancer [5–8], and those with tracheostomy and/or ventilator dependency without neurologic/structural disturbances that would otherwise precipitate dysphagia [9–12]. Regardless of etiology, the potential health risks that can stem from dysphagia are great and include increased likelihood for malnutrition, pulmonary infection [13], and death [14].

Dysphagia can negatively impact medical recovery, resulting in longer hospitalizations and an increased need for long-term care [15]. Aspiration pneumonia, a common sequela of dysphagia, is associated with a significant risk for morbidity and mortality [16]. It has been reported that in the eight-year period from 1991 to 1998, the number of patients hospitalized for aspiration pneumonia increased by 93.5%, making it the second most common reason for hospitalization [17]. Identifying more effective methods of diagnosis and treatment has been designated as a top priority in rehabilitation research [18] in order to improve the health and quality of life and decrease fatalities in those with dysphagia.

Historically, research has focused largely on the use of compensatory maneuvers while swallowing to prevent aspiration. Postural compensations such as manipulating the head, oral structures, and/or body position [19, 24] have been beneficial to this end. Altering viscosity, volume, and consistency of food and liquid has also proven successful for improving safety and efficiency of oral intake [19, 25, 26]. In addition to the use of compensations, a variety of exercise regimens have been proposed to improve swallowing ability by targeting range of motion [27],

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increasing swallowing effort volitionally or through exercise [28–32], and stimulating the sensory system [33–36]. The use of biofeedback as an adjunct in treatment to increase awareness of swallowing patterns and to help the patient modify, monitor, and challenge performance while executing swallowing maneuvers has also yielded positive results [37–39]. While these endeavors have greatly contributed to the current knowledge base about how the swallowing mechanism responds to treatment, they do not offer much regarding how to best prescribe these interventions for maximum benefit. In addition, many of the most popular therapeutic interventions are based on findings reported from a limited number of small group studies, single-case studies, unreplicated findings, or even clinical intuition. At present, there remain more questions than answers regarding how to most effectively and efficiently approach dysphagia rehabilitation.

While these preliminary levels of evidence are important for building the foundation to discover effective treatments, what is also needed is continued, programmatic investigation with larger group studies and replication of research with implied positive outcomes in order to improve statistical power. In addition, investigation of treatments and, in particular, how exercise-based training regimens are designed and delivered is needed. In recent years there has been a surge in discussions about how current exercise training practices in dysphagia rehabilitation relate to what is known about principles of neural plasticity and muscular adaptation and general principles of exercise training [40–42].

Just as a physical trainer might ask a client his/her goals before prescribing a training program, rehabilitation specialists should also have a clear vision of specific performance goals to be targeted with exercise in swallowing dysfunction. Findings in exercise science and physical rehabilitation literature suggest that the method and manner of training should differ quite significantly whether the goal is to increase strength, speed, endurance, or some combination thereof [43]. Understanding how exercise training can be structured to facilitate and maximize neuromuscular plasticity is an integral component in developing successful treatments. A clear understanding of the mechanisms of neuromuscular plasticity and having clearly defined outcomes is critical for structuring interventions to maximize peripheral and central adaptation for long-lasting improvement in function [44, 45].

The intent of this article is to (1) explore the overriding principles of neuromuscular plasticity with regard to strength training, (2) evaluate how current exercise-training interventions in dysphagia rehabilitation correspond to these principles, (3) discuss how these principles might be incorporated into dysphagia rehabilitation, and (4) postulate directions for future study of normal and disordered swallowing.

Overview of Muscle Structure and Function

Before delving into skeletal muscle response to strength training, a general overview of muscle structure and function is warranted. Muscles contain sarcomeres, which are the smallest functional unit involved in muscle contraction [46]. Contraction is achieved when there is successful binding of proteins (actin and myosin) along the sarcomere causing the filaments to slide toward each other, creating the shortening action of contraction [47, 48]. Bundles of sarcomeres form muscle fibers that are organized with a complex matrix of other structural and connective tissue to ultimately comprise whole muscles. Force production and endurance capabilities of muscles are determined by characteristics of the muscle fibers and their bioenergetic capacity for adenosine triphosphate (ATP) production which provides the energy to fuel contraction. While there are numerous muscle fiber types, those in human skeletal muscle can be generally categorized as slow twitch (Type I) and fast twitch (Type II).

Type I fibers are slower to contract in comparison with other fibers but are more resistant to fatigue due to a more efficient capacity for ATP production through aerobic metabolism. Because of the contractile speed and bioenergetic properties for oxygen consumption during aerobic metabolism, Type I fibers are also described as slow-oxidative fibers. They are relatively smaller in diameter than Type II fibers and, consequently, have a lower capacity for force generation.

By comparison, Type II fibers are larger in diameter and more adept at force generation. Despite more rapid twitch response and greater capacity for force production, Type II fibers are less efficient with energy metabolism and therefore more subject to fatigue. Type II fibers can be further subdivided into Type IIa and Type IIb. At the furthest end of the spectrum is the Type IIb muscle fiber. It has the greatest capacity for force generation but is inefficient because it is fast contracting but easily fatigable. Type IIb fibers are rich in glycolytic enzymes, which fuel anaerobic metabolism for ATP production, making them fast-glycolytic fibers. Finally, Type IIa fibers are considered to possess characteristics of

Type I and Type IIb fibers, making them highly adaptable because they contain a blend of contractile and bioenergetic characteristics of both fiber types. Type IIa fibers are fast-oxidative/glycolytic, having both aerobic and anaerobic capacity for producing ATP.

Whole muscles contain a blend of fiber types, but one type is generally predominant; no muscle contains entirely one fiber type or another. The primary role of a muscle usually dictates the predominant fiber type. Tonically active muscles, such as those used for postural maintenance, are composed of primarily more slow-twitch, highly fatigue-resistant Type I fibers. Those used in a more phasic, forceful, ballistic fashion, as is required for increasing or decreasing joint angle, are composed of mostly faster-twitch, more easily-fatigable Type II fibers.

In addition to the typical Type I, IIa, IIb fibers, oral, pharyngeal, and laryngeal muscles also contain hybrid fibers. Muscles involved in mastication and swallowing exhibit unique fiber types, architecture, and composition, unlike any other human skeletal muscle. Considering that form follows function in determining muscle properties, the uniqueness of these muscles is logical when considering the spectrum of actions undertaken, including respiration and verbal communication as well as mastication and swallowing. In addition, the demand on these muscles may shift quite rapidly from tonic contraction for maintaining airway patency during inhalation to rapid low-force movements during speech to more forceful bursts of activity during chewing and swallowing. While a comprehensive review of this complex topic is beyond the scope of this article, readers are encouraged to refer to a review on the topic by Kent [49] that provides a detailed review of the unique properties of these muscle groups. In addition to unusual fiber types, the more common Type I, IIa, and IIb fibers are found in oropharyngeal muscles, with a predominance of the Type II fibers. As would be expected, there is a relatively high concentration of Type I and Type IIa fibers found in the anterior tongue. This blend of fatigue-resistant Type I fibers and the relatively faster-contracting IIa fibers provide the structural support for the anterior tongue to perform rapid, repetitive, low-force movements during speech production. Alternately, more rapidly contracting, larger-diameter Type IIb fibers congregate toward the tongue base and in the pharyngeal constrictors that produce rapid but more forceful actions during swallowing.

There is a paucity of data on structural adaptations of human oropharyngeal muscle to exercise. It is noteworthy, however, that the existing evidence in both animal and human models suggests that muscles of mastication and swallowing do appear to adapt in response to loading conditions [50–52]. Although structural adaptations in muscle occur in response to increased or decreased activity, there are other adaptations that occur in response to exercise other than fiber type shifts. Determinants of type and degree of adaptation depend on the activity and duration and intensity.

Effects of Training and Detraining

Adaptations to Training

Early changes in strength training are generally the result of modifications in how the nervous system activates the muscle rather than a structural alteration in the muscle itself. Improved performance may be the result of an increased number of motor units recruited or improved speed and coordination of motor unit recruitment [53, 54]. These early alterations in neural activation can improve force production, coordination, and precision of movement. As a training program progresses, strength gains then appear to be more the result of morphologic changes within muscle tissue because the relative contribution of neural factors decreases [53, 54].

Two types of morphologic adaptations that occur in muscle responding to exercise are fiber type shifts and hypertrophy. The contractile properties of the muscle fibers generally shift toward a more slowly contracting, fatigue-resistant phenotype (Type I). Hypertrophy (enlargement of the muscle fiber) is the structural adaptation that affects the true force-generating capacity of a muscle and is usually the primary goal of strength training [46, 53]. Each of these structural adaptations occurs at different times throughout the training period. Reports in the exercise science literature suggest that fiber type shifts (in combination with neural adaptation) may account for early improvements, before the muscle has an opportunity to undergo hypertrophic changes [43]. Although some controversy exists about the exact length of time it takes before hypertrophy occurs in response to strength training, it has been reported that a sufficient degree of hypertrophy can occur as early as five weeks into strength training to consider it the dominant cause for observed changes in performance [43, 46, 55]. The intensity and type of training dictate whether hypertrophic changes will, in fact, occur.

In addition to structural changes in the periphery during the later phases of training, structural changes have also been observed in the central nervous system [56]. While the method and manner of cortical reorganization following volitional strength-training exercise in dysphagia rehabilitation is currently unknown, some studies have demonstrated motor map reorganization in response to sensory stimulation. Hamdy et al. [57] reported that cortical reorganization occurred in patients who exhibited swallowing recovery. Furthermore, in animal studies of skilled motor movement training, structural adaptations have been reported in the central nervous system in the form of synaptogenesis and dendritic branching [58]. These findings from both human and animal models support the notion that the neuromotor system is highly stimulable to experience-dependent adaptation and may include restructuring of the central nervous system as well as the periphery. These studies also provide dysphagia researchers with a model for investigating what level of intensity and duration of training is needed to maximize central and peripheral adaptation. Insights gained from such investigations could help eliminate some of the guesswork in treatment planning by providing guidance to patients and clinicians about expected recovery periods related to rehabilitation efforts.

Adaptations to Detraining

The effects of detraining tend to occur more rapidly than the effects of training. The precipitation of detraining varies for athletes versus those recently trained, because the latter return to pretraining levels more rapidly than do athletes [59]. Skeletal muscle response to detraining includes atrophy, reduced force-generating capacity, and a fiber-type shift toward the fast-fatigable, glycolytic phenotype (Type IIb) [46]. Significant decreases in strength gains can be observed after approximately four weeks following cessation of training [59].

Another detraining condition is that of chronic bedrest. After only four to six weeks of bedrest from usual activity, muscle mass of skeletal limb muscles can decrease dramatically, resulting in as much as a 40% decrease in strength [60]. Individuals with compromised health and those of advanced age are most susceptible to the effects of prolonged bedrest and other forms of muscle disuse [60, 61]. This model of deconditioning from reduced muscle use is provocative with regard to dysphagia. Dysphagic patients are known to elicit spontaneous saliva swallows with less frequency than other hospitalized but nondysphagic counterparts [62]. Furthermore, patients who rely on nonoral feeding methods have less need to activate swallowing muscles. One would assume this could lead to a detraining effect of this muscle group but this theory remains uninvestigated.

Effects of Training and Detraining in Aging

Several changes occur throughout the body with normal aging, and muscle tissue is not exempt. Progressive decreases in strength and rapid force production are attributed to reduced muscle mass. The process of muscle atrophy in aging is multifactorial. Age-induced hormone imbalances are associated with reduced cross-sectional area in aging skeletal limb muscle [63]. Sarcopenia, an age-related reduction in muscle fibers that preferentially affects fast-twitch fibers (Type II) more than slow-twitch fibers (Type I) [64, 65], also contributes to progressive strength decline with advancing age. While there is more than a single contributor to this process, the selective reduction of Type II fibers from sarcopenia may be the mitigating factor for decreased strength in swallowing with normal aging because the oropharyngeal muscles contain a greater percentage of Type II fibers.

In addition to muscle fiber loss with advancing age, there is also a decrease in motor units and remodeling of the motor unit structure [66]. Loss of strength due to these age-related structural degradations is most notable beginning with the sixth decade of life [67–71]. Progressive decrease in activity with aging may also account for some of these deleterious effects and engaging in regular exercise may help stave off some of these negative consequences [72, 73].

It has been reported that exercise training across the lifespan can produce adaptations in muscle and brain resulting in improved motor performance [74, 75]. Improvements in isolated strength and functional tasks in elders who engage in strength training are primarily the result of adaptations in neural activation of muscles in the early states of training followed by hypertrophy of both Type I and Type II muscle fibers [63, 76]. When comparing the strength gains of middle-aged and elderly men, Hakkinen et al. [63] found that exercise-induced structural adaptations follow a similar pattern to that of younger individuals but that the relative contribution of neural factors to overall strength gains is proportionally greater in older individuals. Some investigations of skeletal limb muscle also demonstrate that the rate and maintenance of strength development differs between younger, middle-aged, and older individuals [77].

People of all ages respond to well-designed exercise regimens of adequate intensity, including the frail and advanced elderly, greater than 80 years of age [74]. Maintenance of training effects, however, may differ across the lifespan. A recent study by Toraman [78] revealed differences in maintenance of training effects between two groups of elderly between 60 and 73 and between 74 and 86 years of age. There was no significant difference between the groups after six weeks of detraining following a nine-week exercise program. The maintenance of effects between the two groups diverged, however, after 52 weeks of detraining. While both groups exhibited a decline in function, the decline was greater for the older of the two groups, with the decline reaching levels that were worse than initial baseline levels [78]. Lemmer et al. [79] found that while force production significantly improved in both younger and older subjects, the younger group exhibited a greater proportion of gains over the training cycle. The effects of age on degree of strength development during training and rate of decline during detraining were found to be stable across gender [79]. Following cessation of exercise, elders have been shown to maintain performance above baseline anywhere from 5 to 31 weeks. With continued exercise of once per week, older individuals have been shown to maintain both strength and muscle size after completing an initial strength-training regimen [77, 80]. These findings suggest that maintenance programs are important for prolonging training effects. Because many individuals with dysphagia are of advanced age, the long-term effects of detraining and methods for maintaining effects in this population could be fertile ground for future study. As is suggested in studies of skeletal limb muscle, maintenance exercise programs may be necessary to prevent a loss of the benefits gained during the exercise-training period. The utility and practicality of participating in a maintenance exercise program merits investigation. If maintenance exercise programs do prove beneficial, investigations that query the necessary frequency and intensity of continued activity would be important for structuring manageable but effective programs.

Principles of Strength Training

Exercise efforts that do not force the neuromuscular system beyond the level of usual activity will not elicit adaptations [81]. By challenging the system beyond typical use, adaptations occur to accommodate the increased demand. When considering principles of exercise that have been found effective in other areas of physical rehabilitation, exercise science, and sports training, three general themes emerge: intensity, specificity, and transference [53]. Intensity encompasses the amount of load, volume, and duration of the exercise stimulus. Specificity refers to how closely the exercise task corresponds with the targeted outcome. Transference is implicated in the rationale for using cross-training and nonspecific strength training to ultimately improve function. These three main concepts and their relevance to dysphagia treatment are discussed below.

Intensity

Engaging in exercise that is not intense enough to push the system beyond the level of activity to which it is accustomed will not result in adaptation. The exercise task must exceed usual levels of activity and be performed for an adequate duration (within a session and over time) to trigger the need for change in the system's response [43, 46, 53, 54, 81]. With that premise, intensity can be defined on three levels: (1) the mechanical or resistive load placed on the system, (2) amount or repetition of practice during the training regimen, and (3) duration of training over time. Each of these levels of intensity has proven critical in bringing about neuromuscular adaptations.

Resistive Loading

Swallowing can be considered a submaximal muscular activity, meaning that the muscular force generated to successfully complete the activity is well below the maximal force that can be generated by the muscles involved. Most functional activities performed on a daily basis (e.g., walking, reaching, speaking) do not use maximal muscle force and are therefore considered submaximal activities. Nonetheless, when muscles become weak or muscle activation is otherwise disrupted, the perceived effort with which those "simple" activities are performed becomes much greater, even though the absolute demands for the activity have not changed. For example, an activity usually requiring approximately 10% effort out of the maximal voluntary force-generating capacity of a healthy muscle could be performed quite easily and without much perceived effort. Attempting to perform the same activity with a muscle that is functioning at only half its usual capacity would require a greater percentage of the total force-generating capacity of that muscle. The proportion of potential of force-generating capacity in relation to the effort required to perform a certain task is known as functional (or physiologic) reserve [82]. The less functional reserve that exists in proportion to the force needed to perform an activity, the more quickly the muscle will fatigue and the greater the individual's perception of effort will be.

Strength, in its simplest terms, can be defined as the ability to generate force [53]. To increase the force-generating capacity and therefore functional reserve, the physiologic load must exceed the demand typically encountered. This concept, known as the overload principle [53, 81, 83-85], is important to keep in mind throughout training. Over the course of training, the muscle will increase force-generating capacity; likewise, demand must also be continuously increased in order for strength to continue to improve.

To maximize gains over time, the absolute value of load placed on the muscle must be progressively adjusted over the course of the exercise program. This practice, known as progressive resistance, is necessary to maintain the relative physiologic load as a proportion of the maximal force-generating capacity [53, 81, 83–86]. In strength training, this is expressed as a percentage of the 1-repetition maximum (1RM), i.e., the load one can bear with maximal effort to complete a single repetition. Most strength-training regimens begin with an initial resistive load of approximately 60% of 1RM [43, 55, 83]. Intuitively, one might assume that if 60% of 1RM results in strength gains, then greater loads would produce even greater increases in strength. This theory merits investigation because studies of larger muscle groups have reported that in some muscles training at loads greater than 60% of 1RM is effective only in athletes or other individuals regularly participating in a strength-conditioning program. These studies also suggest that training some muscle groups at loads of 60% 1RM or greater may actually cause overuse injuries, particularly in those who have been inactive or who exercise without adequate rest periods [81, 87].

Although muscle injury with proper exercise is thought to be rare, it does occur. The most common cause of injury is thought to be that of overuse [88]. Micheli [88] reports that the most effective way to avoid injury is to increase training load by no more than approximately 10% per week and to avoid great boosts in volume or intensity. This is the general rule for endurance and strength training in large muscle groups, but the limits of overuse remain unknown for oropharyngeal muscles.

Applying the concept of progressive load to the muscles of mastication and swallowing is less clear because the upper and lower limits of load necessary to force functional and structural adaptations in these muscle groups have not been clearly defined. Because other skeletal muscles respond to loads at or above 60% of 1RM, this seems a reasonable level at which to begin investigating training effects in resistive loading protocols for strength training in dysphagia rehabilitation. Treatments using this approach of overload from 60% to 75% of 1RM in strengthening oropharyngeal muscle for dysphagia rehabilitation have elicited promising results [32, 89, 90].

Isometric lingual strengthening has received increasing attention as a viable treatment option for improving swallowing ability by implementing this more focused approach to strengthening through progressive resistance. Investigations by Lazarus [91] and Robbins [32] revealed that healthy lingual muscle trained at loads at or above 60% of 1RM does respond to isometric strengthening to improve force-generating capacity. Robbins [32, 92] also reported that following an eight-week progressive resistance lingual exercise program using the Iowa Oral Performance Instrument (IOPI) in dysphagic stroke patients, not only did maximal isometric pressure generation increase, but oral pressures during swallowing also improved. In addition, patients in Robbins' study improved swallowing function and safety as measured by the Aspiration-Penetration Scale [93]. Although the isometric lingual strengthening tasks do not directly incorporate swallowing as part of the training regimen, improving the force-generating capacity during tongue-to-palate contact appears to impact swallowing function. The ability to manipulate progressive increases in the pressure-generating goal with isometric lingual strengthening regimens is likely one of the keys to eliciting measurable and functional gains.

Another progressive load-bearing strength-training exercise that has emerged as a potential option in dysphagia rehabilitation is expiratory muscle strength training (EMST) [89, 90, 94]. EMST entails exhaling into a device with a one-way, spring-loaded pressure release valve wherein the threshold to allow release of the valve is set between 60% and 80% of the individual's maximal expiratory pressure. This threshold is re-evaluated and adjusted at regular intervals throughout the training program in order to maintain the relative resistance during exhalation, thus incorporating a progressive load. Kim and Sapienza [94] have postulated that the mechanism by which EMST may improve swallowing ability is through afferent stimulation to brain stem swallowing centers through peripheral sensory receptors in the tongue and oropharynx and by strengthening oropharyngeal, laryngeal, and supralaryngeal muscles involved in swallowing. This type of training could exploit the principle of transference by directly training the common neural substrates and muscles activated in both respiration and swallowing.

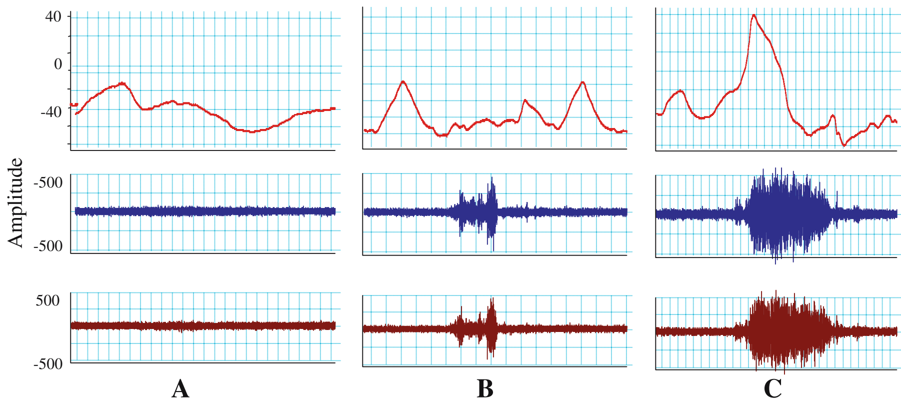

Fig. 1. Electromyographic (EMG) activity of the submandibular muscles during rest breathing (**A**) and breathing through an expiratory muscle strength trainer set at 25% of maximum expiratory pressure (**B**) and 75% of maximum expiratory pressure (**C**). Respiratory flow is shown in the top, with flow being measured in cmH_2O. The middle and lower graphs represent the left and right suprahyoid region, respectively, with raw surface EMG data measured in microvolts.

Unpublished pilot data in a healthy adult volunteer seen in Figure 1 suggests that the task of exhaling through a device using high expiratory force causes an increase in activity of the suprahyoid muscles. Figure 1 demonstrates surface electromyography of suprahyoid muscle group increasing with progressive increases in pressure threshold load of the EMST device. Aside from the potential effect of EMST on suprahyoid muscle recruitment, EMST is known to improve expiratory driving pressures for cough [95], which could aid in the effectiveness of redirective cough in the event of aspiration or penetration of material into the airway.

Other than emerging therapies such as EMST and lingual strengthening protocols incorporating progressive resistance, there is little in the clinician's arsenal for imposing quantifiable load, let alone progressive load, on muscles for dysphagia rehabilitation. Regardless of this limitation, there are some creative methods that can be used to impose some degree of loading and to manipulate force production in swallowing musculature.

The simplest method of eliciting increased muscular effort during swallowing is with an effortful swallow maneuver. With this technique a patient is instructed to swallow with maximal effort either with or without ingesting a bolus. It has been reported that use of an effortful swallow can result in increased pressure generation between tongue and palate during a swallow [29] and between tongue base and pharyngeal wall [96]. Huckabee and Steele [97] found that instructing individuals to emphasize tongue-to-palate contact during effortful swallowing, pharyngeal and oral pressure generation was significantly enhanced. It may be possible to further increase the degree of muscle activation during effortful swallowing by introducing a high-viscosity bolus during the activity [98, 99]. Miller and Watkin [98] found that duration and amplitude of lingual force production progressively increased when participants swallowed boluses of increasing viscosity. This evidence suggests that altering bolus viscosity may offer a practical method of loading lingual muscle while swallowing. A limitation of this approach would be the difficulty in quantifying and progressively manipulating load over time.

The Mendelsohn maneuver [28] has also been employed to increase strength and range of motion. This maneuver may also be performed either with or without ingesting a bolus. In this technique a patient is asked to swallow but then to "hold" the larynx at the peak of the swallowing gesture, before it begins its descent. This should facilitate increased effort and neuromuscular activation and may also improve endurance in that the patient is instructed to hold the larynx in its highest position for a period of time. In fact, Ding et al. [100] reported a significant increase in suprahyoid muscle group activity when the Mendelsohn maneuver was performed compared with normal swallowing. While this may provide some degree of load and endurance training by resisting laryngeal descent after a swallow, like the effortful swallow exercise, it does not allow for progressive manipulation of physiologic load over time or the objectification of the amount of load imposed during the exercise.

The tongue-holding maneuver, commonly referred to as the Masako maneuver [101], also provides some degree of passive load to the system while performing a dry swallow and it is implied that this technique will increase muscular work. This maneuver entails swallowing while the tongue is maintained in an anterior position, held between the teeth. Again, like the Mendelsohn maneuver and the effortful swallow, manipulation of progressive physiologic load along the continuum of the training program is not possible which may limit the amount of strengthening that could otherwise be possible if the amount of load could be increased over time.

Another exercise regimen that incorporates some degree of passive resistance is the Shaker Head Lift [102]. This technique involves a combination of isometric and isokinetic contractions involving the strap muscles of the neck and suprahyoid musculature as it imposes a degree of loading by lifting the weight of the head against gravity. The exercise begins with the isometric task of lifting the head to look at the feet while in the supine position for one full minute, three times, with one-minute rest periods between each static head lift. The technique then commences with the isokinetic task of lifting the head for 30 consecutive repetitions. The prescribed regimen involves performing the isokinetic-isometric technique three times per day over a six-week training period. Shaker et al. [102] reported that following this exercise regimen, persons with dysphagia significantly improved with respect to the following: hyolaryngeal excursion, degree of upper esophageal sphincter opening, amount of postswallow pyriform sinus residue, and occurrence of aspiration after the swallow. The improvements were attributed to increased strength in the suprahyoid musculature following the exercise protocol. Because the suprahyoid muscles are not typically accustomed to lifting the weight of the head within the manner and degree of intensity outlined in the Shaker Head Lift exercise protocol, the overload principle does appear to be incorporated in this paradigm. On the other hand, the amount of load is not easily quantifiable and is not progressively manipulated over the course of the exercise program. This limitation may influence the impact of the program over the duration of the protocol because the amount of work performed is less in relation to the expected increases in maximal force-generating capacity over the course of training.

Repetition and Volume of Practice

In addition to exposing the muscle to adequate amounts of load during strength-training efforts, the manner in which these efforts are structured can also affect outcomes. The volume of exercise can be manipulated by adjusting the number of repetitions performed in sequence, total sets completed, the length of rest periods between sets, the number of days of exercise per week, and the number of weeks the exercise is performed. While dose-dependent studies investigating these parameters for exercise in oropharyngeal muscle do not exist, the importance of studying this variable is impressive when considering investigations of this kind involving other skeletal muscle groups.

In a meta-analysis of the exercise training literature of skeletal limb muscle, Rhea et al. [87] found that variations in exercise dose significantly altered outcomes, with detrimental results occurring with overly aggressive training regimens. Furthermore, they found a substantial number of studies suggesting that trained and untrained individuals respond quite differently to exercise volume and intensity with respect to different muscle groups throughout the body. Some muscle groups responded optimally to only one set of exercise at 60% of 1RM [87]. Engaging in additional sets did not cause harm but they were of no measurable benefit. Furthermore, the number of repetitions within a set also altered outcomes in skeletal limb muscle. While the primary objective of strength training is to increase force-generating capacity, the manner in which training is approached may impact other qualitative aspects of movement such as power (amount of work performed over a given amount of time) and endurance (the ability to sustain activity over time). If building strength and endurance is the goal, 8–12 repetitions per set of exercise proved most effective, while 6–8 repetition sets elicited greater outcomes for generating strength with greater power [81, 87].

Findings of dose-response studies of other skeletal muscles raises the question of whether these seemingly minute variations in the structure of an exercise program might impact these subtle but potentially important movement patterns during swallowing. It may be that simply altering the number of repetitions and sets of an exercise regimen for oropharyngeal muscles might differentially impact outcomes of strength, endurance, and power during swallowing. Perhaps patients exhibiting greater impairment toward the end of a meal might benefit from treatment regimens consisting of strength training with 8–12 repetition sets. On the other hand, patients exhibiting a generally weak swallow might benefit more from treatment structured in sets of 6–8 repetitions with high load demands. While exercise techniques and maneuvers are available to the dysphagia clinician, the optimal dose (i.e., number of sets and repetitions over a set amount of time) has not been determined. Questions regarding the upper and lower limits of load, volume, and intensity are important to consider as our field moves forward in the investigation of how both healthy and disordered oropharyngeal muscles respond to exercise training for maximal gains. Answering these questions of dose will aid in determining the most efficient and effective training programs.

In addition to impacting nuances of performance outcomes, the volume of exercise prescribed can affect compliance with an exercise program [81]. Anyone who has attempted to undertake an exercise program will attest to the notion that the most successful training program is one that employs an adequate volume of exercise to evoke measurable improvements balanced with a feasible degree of effort. There are many challenges for researchers studying dysphagia and for clinicians treating it. One of the more important challenges is to strike a balance between structuring exercise programs with adequate volumes of work for eliciting functional change and the constraints imposed by the patient's situations (e.g., financial, reimbursement issues, time demands). Easterling et al. [103] took on this challenge in an investigation of compliance and program duration with the Shaker Head Lift exercise protocol.

In a six-week training regimen of the Shaker Head Lift protocol, Easterling et al. [103] evaluated outcomes of compliance, swallowing physiology, and time to attainment of both isokinetic and isometric goals. Of the 26 healthy adults enrolled in the study, 7 completed the six-week regimen. Of those 7, 100% attained the isokinetic goal and 74% attained the isometric goal. Four of the participants agreed to a fluoroscopic examination of swallowing. All participants examined demonstrated gains in fluoroscopic swallowing measures. The authors concluded that a more structured and progressive introduction to the protocol is needed and that this, along with increased education of participants, would likely improve compliance and outcomes. This investigation is an excellent illustration of the utility of investigating feasibility and the durational effects of exercise for developing a successful training program. Findings from this type of inquiry will provide guidance for continued investigations intended to further refine this technique and identify the optimal volume and duration of the regimen.

Specificity

Change in overall performance due to exercise involves a complex constellation of both central and peripheral adaptations. By implementing task specificity into a training regimen, these collections of factors are all focused toward one common goal. Task specificity in training refers not only to endurance training versus strength training, but also to the actual task being undertaken. Examples in exercise science literature illustrate the importance of task specificity in training.

Magel et al. [104] reported that athletes who were endurance-trained in one form of cardiovascular exercise did not demonstrate a training effect in other forms of endurance-geared cardiovascular exercise. Specifically, participants who underwent swim training demonstrated an increase in endurance and cardiovascular performance during swimming. However, when endurance and cardiovascular performance were measured during running, no appreciable training effect was observed [104]. Although it seems intuitive that endurance training targeting the same underlying system (i.e., cardiovascular performance) would carry over to improved performance in related activities (i.e., all cardiovascular exercise), the evidence suggests that this is not necessarily the case. Simply targeting "endurance" or "strengthening" of a specific system or muscle group in a general sense may not necessarily be enough to force the types of adaptation necessary to improve performance of a specific task. The greatest gains for a particular activity are elicited when the training task resembles the end-goal as much as possible. Therefore, if becoming a better runner is the goal, then running should be the training task; if improved swallowing is the goal, then swallowing would be the optimal training task. In some instances, however, this may not be possible.

Treatment regimens incorporating task specificity within a framework of adequate load, repetition, volume, and duration to force central and peripheral adaptations are certainly ideal. In other words, having patients swallow with a controlled proportion of physiologic load would likely be the optimal training activity for the rehabilitation of swallowing function. However, clinicians are frequently charged with the task of rehabilitating deglutitive function in individuals who cannot even remotely demonstrate the postures necessary for controlling and manipulating a bolus in the oral cavity, let alone initiate a pharyngeal swallow. These practical obstacles can sometimes prove difficult for simple application of some of the aforementioned principles of specificity, volume, and intensity. Given this situation, general strength training may be implemented as a precursor to practicing functional tasks [82, 105–110]. Strength training has been shown to improve performance in limb and whole-body submaximal dynamic functional activities when used in conjunction with or as a precursor to more task-specific training. In essence, participation in isolated strength-training tasks may impact ability during dynamic tasks by building a foundation of force-producing capacity, increasing functional reserve, and priming the neuromuscular system for activity. This transference of effects from isolated force-generating exercise tasks to dynamic activities has great implication for dysphagia rehabilitation.

Transference

While specificity of exercise is a well-established principle in the exercise science literature, another intriguing concept that has also been shown effective is that of transference. Athletes frequently engage in isolated exercise drills to fine-tune specific components of movement in order to improve overall athletic performance. Some studies show that implementing rote practice of specific movements (e.g., "drill" practice) can positively influence performance in dynamic activities by improving somatosensory processing and optimizing neuromuscular firing patterns [106, 107, 109]. Complex neural, biochemical, and hemodynamic systems that are activated during exercise can have widespread effects throughout related or parallel systems of the body. Transference might explain how tasks that incorporate sound exercise principles but are not swallowing-specific (i.e., EMST, lingual strengthening, Shaker Head Lift) may improve swallowing function. The principle of transference may also account for improvements noted in the swallowing ability of Parkinson's patients following an intensive regimen of Lee Silverman Voice Treatment (LSVT), an intervention that focuses on loud voice production through a variety of tasks [111].

LSVT is an intervention program that was originally designed to improve voice and speech production in patients with Parkinson's disease. It has been reported that this intense, high-effort treatment targeted at improving respiratory support and vocal fold adduction has also impacted swallowing function. Sharkawi et al. [111] reported a significant improvement in both oral and pharyngeal swallowing measures as assessed through pre- and post-treatment videofluoroscopy following an intensive four-week LSVT intervention program. The authors postulate that the improvement noted in the seemingly disparate function of swallowing is due to the habituation of increased effort, which may provide an overabundance of stimulation to the neuromuscular system associated with the entire aerodigestive tract. Will and Ramig [112] suggested that increased recruitment of suprahyoid and laryngeal musculature during high-effort tasks during LSVT might contribute to increasing strength in these muscles, which are critical in airway protection during the swallow. Although the intensity of effort and volume of practice employed with LSVT certainly overloads the system during treatment, much like other exercise-based interventions for dysphagia rehabilitation discussed thus far, the amount of load is not known or manipulated over the course of the training period.

Isolated strength-training regimens that incorporate progressive resistance have been shown to transfer to improved performance in functional activities. In studies of skeletal limb, isolated strength-training tasks undertaken as a precursor to or in conjunction with dynamic tasks resulted in greater functional outcomes when compared with simply training the dynamic exercise alone [107, 109, 113]. In addition, isolated strength training can be particularly effective for improving function in frail or decompensated individuals with significant weakness [82, 105, 110].

Buchner and de Lauter [82] postulated that improvements in functional tasks following isolated strengthening exercises may be the result of increased physiologic reserve. They propose that the relationship between strength and function is curvilinear in that gross maximal force-generating capacity is most highly correlated with function up to the point of threshold of relative strength necessary for a targeted task. The correlation between strength gains and function tends to plateau after the point of threshold, and additional gains in strength then contribute to physiologic reserve but do not necessarily impact functional skill [82]. By increasing force-generating capacity beyond the strength threshold for a task, individuals then execute activities using a lesser proportion of their functional reserve, leading to less perception of effort. While there are no known studies of the effect of functional reserve on performance in oropharygneal muscles, this concept was pointed out by Luschei [114] who stated that to produce rapid articulatory movements during speech, the underlying strength must be greater than expected to meet these demands. Determining the degree that functional reserve impacts safety, efficiency, and perceived effort in swallowing would be useful in determining training goals.

Another concept that substantiates the utility of isolated motor tasks impacting subsequent performance is that of postactivation potentiation (PAP) [115]. In a review of how PAP might affect motor performance, Sale [75] explains that skeletal muscle, at any given point in time, is affected by its contractile history. This is readily seen in an extreme example when an individual fatigues, a situation wherein prolonged history of use ultimately results in failure. The concept of PAP appears to be an underlying rationale for implementing "warmup" exercises before an athletic event (e.g., baseball player practicing a swing with a weighted bat before attempting to hit the ball). The concept of PAP suggests that when the muscle engages in contractile activity (but not so much to induce fatigue), the muscle is essentially primed for subsequent use. The mechanism of PAP is explained by increased biochemical activity and motor unit activation that positively impacts contractile ability and efficiency. With regard to strengthening activities specifically, it appears that PAP can impact rate of force development that may be of interest with regard to rapid movements necessary for airway protection during swallowing. In his review, Sale [75] indicates that the application of PAP to increase human motor performance is a fertile area for future research. This concept provides a methodologic framework for using strengthening activities as a method of priming the muscle for subsequent task-specific activity. Although there are no formal studies investigating the use of priming the system before swallowing tasks, this may be an interesting area to investigate. If the principles of PAP apply to oropharyngeal muscle, then engaging in activities that would increase neuromuscular activation before an exercise session or before oral intake might prove beneficial by improving performance.

Application of Exercise Principles in Swallowing Rehabilitation

By manipulating viscosity, bolus size, and/or position, many persons with dysphagia are able to continue safe oral intake, even if only in a therapeutic manner with direct supervision. The use of these modifications helps facilitate the task-specific activity of swallowing. Simply swallowing food, liquid, or saliva, however, is not an activity that can provide the degree of load that is necessary to force adaptations in the neuromuscular system to increase in strength. Even so, some creative solutions have been presented in the literature in an attempt to introduce some degree of load during swallowing activities to build strength.

In swallowing rehabilitation today, there exists a repertoire of treatment interventions incorporating manipulations of swallowing gestures and strengthening activities involving subsystems that require the use of oropharyngeal muscles but do not involve the task-specific activity of swallowing. These treatment approaches may capitalize on principles of transference, build functional reserve, and promote more efficient activation of motor patterns, as is seen in skeletal limb muscle.

Studies implicating the functional utility of strength training in skeletal limb muscle provide theoretical rationale for strategically targeting more structured exercise regimens in dysphagia rehabilitation. Approaching strength training in this way may improve general force-generating capacity, increase functional reserve, stimulate motor unit recruitment, and prime the system for the intended activity. These effects may lessen perceived effort, allowing subjects to consequently participate in longer bouts of task-specific exercise [116]. With that being said, strength training can be a potent treatment alone, but perhaps may elicit even greater effects when implemented as an adjuvant therapy to task-specific swallowing practice.

Strength-training programs in dysphagia rehabilitation may be more effective if tailored to target different activation patterns encountered during various swallowing conditions. For example, it may be beneficial to structure strength-training tasks aimed at improving power by targeting rapid force generation, if the goal is to improve the driving force during tongue base retraction at the initiation of the pharyngeal swallow. On the other hand, it may be beneficial to target sustained static contraction during treatment if the aim is to improve endurance of sustained muscle activity such as that encountered during consecutive swallows. Structuring treatments with specific numbers of sets and repetition may also lead to more specific performance gains. The effect of structuring training efforts in such a way for dysphagia rehabilitation remains to be seen.

The current therapies reviewed here each touch upon some of the principles of effective strength training. Deciphering whether strength training can drive adaptations in the neural substrates of swallowing or if it will result in lasting, functional change begs further inquiry. Specifically, the impact of swallowing rehabilitation efforts on central mechanisms is an area that has not been thoroughly addressed in the literature. The challenge is to continue investigation of therapies that apply and/or manipulate different aspects of strength-training principles to optimize outcomes through the most efficacious, efficient, effective approaches possible.

Implications for Future Research

Robey and Shultz [117] proposed a research model for clinical outcomes in communication sciences and disorders. This model is structured upon a progression of investigations moving from explorations first of efficacy (the possibility that therapeutic benefits may result under optimal conditions), then of effectiveness (the probability that therapeutic benefits will result under typical clinical conditions), and, finally, of efficiency (the cost versus the benefit of a treatment protocol). To optimally investigate the responsiveness of the neuromuscular system underlying swallowing to strength training, the investigations should incorporate, as possible, the key principles of strength training and adhere to the standards of the research outcomes model proposed by Robey and Shultz [117]. Adhering to the rubric of systematic investigation in this manner calls for the consideration of the impact of exercise regimens not only on function but also on disability and societal impact in later stages of investigation.

The International Classification of Functioning, Disability, and Health (ICF), put forth by the World Health Organization and ratified by the World Health Assembly in 2001 [118], provides the framework for conceptualizing the differences between body functions (such as physiologic measures of swallowing) and one's ability to function in a typical environment (as one would when eating meals socially). For researchers, this model provides a guide for delineating which aspect of ability a research endeavor may address and also how these efforts may or may not relate to the overall participation in life events. The ICF also helps illustrate that simply improving performance on a physiologic measure of movement may or may not result in the ultimate goal of rehabilitation: maximizing participation and quality of life. As the field of dysphagia rehabilitation progresses with its methods of strength training, it is critical to also be mindful of this ultimate outcome. Dysphagia researchers can glean insight on the importance of the distinction between the potential disparity between physical function and disability.

In a meta-analysis of whole-body aerobic and resistance exercise programs spanning between 1985 to 2000 in older subjects, Keysor and Jette [119] argue that the existing evidence does not provide support for decreasing disability. While the studies in this meta-analysis demonstrated gains in measures of function, the impact on disability and the level of participation was not readily appreciated. They suggest that this may be the result of methodologic limitations and also of the shortsightedness of not investigating the impact of these treatments beyond measures of impairment and functional limitation. In this scenario, biomechanical measures of function appear to serve as surrogate endpoints. By definition, a surrogate endpoint is a "laboratory measurement or physical sign used as a substitute for a clinically meaningful endpoint that measures more directly how a patient feels, functions, or survives" [120]. So although it may seem logical to assume that increased strength results in increased ability, it is also important to measure the impact on disability rather than assuming a causal relationship between improvements in measures of function and decreased disability. This notion only strengthens the case for looking beyond simple biomechanical measures to capture the true impact an intervention has on one's ability to perform tasks, increase functional abilities, and ultimately improve participation. As suggested by Robey and Shultz [117], the key to discovering the overriding effectiveness and efficiency of a treatment is in a stepwise fashion that starts with the investigation of efficacy in impacting function.

Logemann [42] recently affirmed the importance of and need for systematic investigations, particularly in the field of swallowing and swallowing disorders. Foundational work is needed to illuminate the method and manner in which the normal systems adapt in response not only to specific exercise techniques but also to varying levels of intensity. A more thorough understanding of the typical response of a healthy neuromuscular system will provide the knowledge base upon which interventions can be built for remediation of dysphagia in disordered populations. A model of typical physiologic adaptations in response to exercise will provide researchers and clinicians with a framework upon which to scaffold new interventions that can be investigated in disordered populations.

It is encouraging that strength training and the principles governing effective methods for training have begun to infuse exercise-based investigations in dysphagia rehabilitation. In addition to the principles of intensity, specificity, and transference discussed in this article, other factors such as optimal timing for initiating interventions and the effects of detraining are also fertile areas for investigation.

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