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Review Article

A Scoping Review of the Characteristics of Activity-based Therapy Interventions Across the Continuum of Care for People Living With Spinal Cord Injury or Disease

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Rehabilitation;
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Abstract *Objective:* To identify the characteristics of activity-based therapy (ABT) that individuals with spinal cord injury and disease (SCI/D) participate in across the continuum of care.
Data Sources: A search of 8 databases was conducted from inception to 4 March 2020: Medline, CINAHL, Embase, Emcare, PEDro, APA PsycINFO, Cochrane Database of Systematic Reviews, and the CENTRAL. The search strategy used terms identifying the population (SCI/D) and concept (ABT).
Study Selection: Original studies involving individuals with SCI/D ≥16 years of age participating in ABT interventions for >1 session were included in the review. The Joanna Briggs Institute guidelines for scoping reviews were followed. The initial search produced 2306 records. Title, abstract, and full-text screening by 2 independent reviewers yielded 140 articles.

List of abbreviations: ABT, activity-based therapy; JBI, Joanna Briggs Institute; MMAT, Mixed Methods Appraisal Tool; PCC, Population, Concept, and Context; PRISMA-ScR, Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews; SCI/D, spinal cord injury and disease.
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Data Extraction: Data extraction was conducted by 3 independent reviewers and charted according to key themes. Data fields included participant demographics, ABT interventions, exercises, parameters, technology, and setting. Data synthesis included frequency counts and descriptive analysis of key themes.

Data Synthesis: Eighty percent of participants were male. Eighty-seven percent of studies included individuals with tetraplegia (26% exclusive). Fifty-six percent of studies occurred in a research lab. Fifty-four percent of studies were single modality interventions encompassing the whole body (71%). Sixteen main types of ABT exercises were identified. The most common were treadmill training (59%), muscle strengthening (36%), and overground walking (33%). Electrical stimulation (50%) and virtual reality (6%) were used in combination with an ABT exercise. Eighty-four types of parameters were identified. Six were general intervention parameters and 78 were specific to the type of ABT exercise. Sixteen main categories of technology were reported. The most common were motorized treadmills (47%) and transcutaneous electrical stimulation (44%).

Conclusions: The characteristics of ABT are diverse in scope. The results will inform the content to include in tools that track ABT participation and performance.

Neurological disorders and diseases are diverse in scope, with spinal cord injuries and diseases (SCI/D) being no exception. The nature of SCI/D may be attributable to traumatic or non-traumatic causes and lead to extensive motor and sensory deficit, as well as a multitude of secondary impairments affecting all body systems.[1-4] Until recently, conventional rehabilitation has been the standard of care, providing a targeted approach to reducing secondary complications and maximizing function and independence. For the most part, treatment plans catered to an individual's level and severity of injury emphasize a patient's reliance on compensatory strategies and adaptive aids to perform activities of daily living.[5] After inpatient rehabilitation, community-dwellers rely on physical activity through exercise, fitness and sport as a means to maintaining overall health and function.[6-8] However, although beneficial in reducing secondary complications and improving mental health, overall well-being and quality of life,[9-11] exercise, and sport often target muscles above the level of injury, and hence, may not promote neurorecovery.

Subsequently, activity-based therapies (ABT) have emerged as an alternative to conventional rehabilitation by offering "interventions that provide activation of the neuromuscular system below the level of lesion with the goal of retraining the nervous system to recover a specific motor task."[5] Distinct features of ABT include the high exercise intensity, many movement repetitions, and a high frequency of both the program and individual exercises. The duration of an ABT program can extend up to 5 hours daily.[12-15] Components of ABT include load-bearing exercises, task-specific movements, massed practice, sensory stimulation, and external facilitation combined with motivated mental effort.[13,16-18] Various types of technology and equipment, ranging from low to high in complexity, are often incorporated into an ABT program and may be used to support, assist or challenge an individual during a specific exercise.[18,19] In addition to neurorecovery, which leads to improved function and independence, ABT has numerous health benefits including a reduced risk of cardiovascular and metabolic disease, improved body composition, and psychological well-being.[13,17,20,21]

In 2019, the ABT Community of Practice, previously named the Canadian ABT Working Group, was formed to address the need to augment the quality of and access to ABT across Canada. The multi-stakeholder group, which included individuals living with SCI/D, identified 5 key priorities, one being the development and implementation of tools that individuals living with SCI/D, clinicians, and health systems could use to track the details of participation in an ABT program.[22] A tool of this nature could assist individuals with SCI/D to track and evaluate their progress and motivate them to continue on with their therapy. A tracking tool may also guide clinicians in treatment planning and performance monitoring, determine the effectiveness of a specific therapy or technology and provide information to funders and insurers. At the health system level, a tool may help to contribute to the development of ABT practice guidelines concerning the optimal delivery and dosing of ABT and support decision-making for funding, program delivery, and practice change.

The first step toward tool development is item generation, which may include a review of the literature for existing items and tools, and consultations with experts to ensure the tool is comprehensive and achieves content validity and clinical relevance.[23,24] To determine the items to include in an ABT tracking tool, the characteristics of ABT must first be identified. This process ideally lends itself to a scoping review as these types of reviews are favorable when the research question is broad in scope and there is limited agreement among experts.[25,26]

In the absence of any relevant reviews that describe the characteristics of ABT or tools that track engagement in ABT across the care trajectory,[13-15,20,27-30] we conducted a scoping review to identify the characteristics of ABT that people living with SCI/D participate in across the continuum of care. Review findings will provide the data collection items to incorporate in an ABT tracking tool.

Methods

The Joanna Briggs Institute (JBI) guidelines were used as a framework for this scoping review.[26,31] The objectives, eligibility criteria, search strategy, and data synthesis plans were detailed in an a priori protocol and registered with the Open Science Framework in March 2020 (https://osf.io/ac2qu/).[32,33] No significant revisions were made to the protocol. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist was used to report the results of the scoping review.[34]

The scoping review questions were framed to reflect the Population, Concept, and Context (PCC) structure outlined by the JBI guidelines (see table 1).[31] As such, the primary review question was 'What are the characteristics of ABT (concept) that have been used across the continuum of care (context) with individuals living with SCI/D (population)?' Secondary review questions further explored the population and context (see table 1). For population, we decided to examine ABT characteristics according to level of injury (ie, paraplegia or tetraplegia) and sex and gender. We expected the types of ABT exercises performed by individuals living with tetraplegia to differ from those performed by individuals living with paraplegia; for example, ABT exercises focused on the upper limb would be relevant only to those with tetraplegia. There are no known sex and/or gender differences in ABT participation; however, sex and gender roles are known to influence sport and exercise participation in able-bodied individuals.[35] Moreover, women with SCI/D may show greater natural neurologic recovery than men,[36] which is noteworthy given ABT's emphasis on promoting neurorecovery. As the questions of this review were broad in nature, the eligibility criteria were similarly kept broad in scope. The eligibility criteria followed the PCC framework and are presented in table 2.

The search, from inception to 4 March 2020, included the following 8 databases: Medline, CINAHL, Embase, Emcare, PEDro, APA PsycINFO, Cochrane Database of Systematic Reviews, and the CENTRAL. Based on the review objective and volume of records retrieved in the initial search, the team members decided against conducting a secondary search as they did not anticipate any additional ABT characteristics arising from studies published after March 2020. A full Medline search strategy can be found in Appendix 1. Team members also searched the reference lists of all included studies and review papers identified through the search for any additional relevant materials.

Screening and selection

Initial screening

Records retrieved from the search were uploaded to Mendeley V.1.19.3 (Elsevier, London, UK) and duplicates were removed. Records were then imported to Covidence V.1513 (Veritas Health Innovation, Melbourne, Australia). A random sample of 10 records was independently screened by 2 team members (A.K. and K.C.) to assess eligibility for inclusion in the review based on the eligibility criteria previously described. One hundred percent agreement was reached between the 2 screeners and they proceeded to independently screen the titles and abstracts of the remaining returned records. Discrepancies were discussed and resolved by a third team member (K.E.M.). Three additional items: sports, graded exercise testing performed over more than one testing session, and active registered trials posted on clinicaltrials.gov were added to the list of exclusion criteria. All included sources moved on to full-text screening.

Full-text screening

Following the eligibility criteria previously described, 2 team members (A.K. and K.C.) independently screened a random sample of 10 full-text articles to assess eligibility for inclusion in the review. Discrepancies were discussed with a third team member (K.E.M.) and an additional random sample of 10 articles was screened by 2 team members (A.K. and K.C.). Eighty percent agreement was reached and the 2 team members (A.K. and K.C.) proceeded to independently screen the remaining full-text articles, documenting reasons for exclusion where applicable. Discrepancies were discussed and resolved with a third team member (K.E.M.). Two authors were contacted to request full-text of their papers; however, no response was received. One article was translated from Spanish to English and then excluded.

Data extraction and charting

Following a review of a random sample of 5 included articles, the research team (K.E.M., A.K., and K.C.), along with a key stakeholder (S.M., physical therapist), developed a charting table in Microsoft Office Excel (2007) that aligned with the study objective and review questions.[31] The data extraction fields selected were organized in the charting table to reflect the PCC framework[31] as described below

Table 1 Review questions

Primary review question		What are the characteristics of activity-based therapies (ABT) (concept) that have been used across the continuum of care (context) with individuals living with spinal cord injury and disease (population)?
Secondary review questions	To further explore the population	What ABT have been used with individuals living with paraplegia compared with individuals living with tetraplegia?
		Does ABT participation differ between sexes and gender identities?
	To further explore the context	How does the ABT in acute care, rehabilitation and community settings differ?

Table 2 Eligibility criteria

Inclusion Criteria	Exclusion Criteria
• Study participants reported as having a diagnosis of SCI/D because of a traumatic or non-traumatic cause. • All neurologic levels of injury (ie, cervical, thoracic and lumbar segments). • All degrees of injury severity (ie, American Spinal Injury Association Impairment Scale (AIS) classification of A, B, C, or D). • Individuals with SCI/D may be at any stage in their recovery; that is, acute, sub-acute or chronic stages. • Intervention that meets the following definition of ABT: "Interventions that provide activation of the neuromuscular system below the level of lesion with the goal of retraining the nervous system to recover a specific motor task."[7] • ABT may occur in any setting (ie, acute care, inpatient and outpatient rehabilitation, private and non-profit community-based clinics and home programs) and any country	• Animal studies. • Literature reporting on individuals less than 16 years of age for who the approach to rehabilitation would likely be pediatric focused (eg, play based). • Studies focused on congenital causes of spinal damage (eg, spina bifida). • Studies reporting only one session of ABT. • Studies reporting on exercises targeting muscles above the level of injury only. • Systematic or scoping reviews, meta-analysis, conference proceedings, abstracts, books, book chapters and any other secondary sources of data. • Active registered trials posted on clinicaltrials.gov* • Sports* • Graded exercise testing performed over more than one testing session.*

* Exclusion criteria were added at the screening stage.

(see supplement table S1, available online only at http://www.archives-pmr.org/): study characteristics: title of article, first author, year of publication, type of study design, and study aim; population: eligibility criteria, participant demographics, injury characteristics, number of participants, and adverse event(s); concept: intervention modality, region of the body targeted, type of ABT intervention and exercises, training parameters, control group intervention (if applicable), duration of session, frequency of intervention, duration of intervention, number of sessions and/or total number of hours of intervention, technology used, type of assistance required, outcome measures, time points of outcome measures, and results; context: country(ies) where the intervention occurred and setting.

Three team members (A.K., K.C., and S.M.) completed an independent review, data extraction, and charting of 3 included articles to compare for accuracy and consistency. Discrepancies were discussed and resolved with a fourth team member (K.E.M.). An additional 6 included articles were reviewed until all team members were satisfied with the quality of the data extraction and charting. The remaining articles were divided between 3 team members (A.K., K. C., and S.M.) to independently review and complete data extraction and charting. One team member (A.K.) reviewed all extracted and charted data for quality assurance. Three team members (K.E.M., A.K., and K.C.) met weekly to discuss progress, verify the extracted data, and resolve any issues through an iterative process. No revisions were made to the column headings of the charting table. All missing data were documented and included in data synthesis reporting.

Critical appraisal

Most studies were expected to be quantitative in nature (ie, randomized and non-randomized trials), accordingly, the modified Downs and Black checklist was selected as the appropriate appraisal tool to evaluate the quality of the available evidence.[37-39] The modified Downs and Black checklist contains 27 items that are divided into 5 subscales: reporting (10), external validity (3), internal validity-bias (7), internal validity-confounding (selection bias) (6), and power (1).[39] Studies were scored a 0 or 1 on all items, except one which scored between 0 and 2, giving a maximum possible score out of 28.[39] Higher scores signified greater methodological quality and followed the categorizations suggested by Methajarunon et al., where scores greater than 19 were considered "good," between 11 and 19 "moderate," and less than 11 "poor".[40] The Downs and Black checklist has high internal consistency, good face and criterion validity, and good test-retest and inter-rater reliability.[37,38] Two team members (A.K. and K.C.) independently scored 3 articles to assess methodological quality. Discrepancies were discussed with a third team member (K. E.M.). Two additional rounds of scoring occurred with 3 articles each time until greater than 75% agreement was achieved by the final round. The remaining articles were then divided between the 2 team members (A.K. and K.C.) and independently scored.

Studies retrieved from the search that were qualitative or mixed methods by design were assessed for methodological quality using the Mixed Methods Appraisal Tool (MMAT).[41] The MMAT included 2 screening questions and 5 methods-related questions. Studies were graded on each criteria (ie, Yes, No, or Can't tell) along with room for comments to determine methodological quality. A descriptive summary was used to assess the methodological quality of the articles.[42] The MMAT demonstrates good validity and reliability.[43,44] Since few qualitative or mixed methods studies were expected to be included in this review, only one team member (A.K.) appraised the included articles. Any issues were discussed and resolved with another team member (K.E.M.).

Data synthesis

The source selection process of included articles was descriptively summarized and presented in a PRISMA-ScR flow diagram.[26,34] The PCC framework and review questions were used to guide the data synthesis process. Descriptive statistics (eg, frequency counts) were used to illustrate the sources of evidence, participant demographics, and injury characteristics. To address the primary review question, the characteristics of ABT (ie, type of ABT and their associated technologies and parameters) were summarized using descriptive statistics. To address the secondary review questions, the types of ABT were compared between sexes, genders, level of injury, and health care setting using descriptive statistics. Several data extraction fields were added during data synthesis to simplify reporting. Missing data were noted. The complete data extraction table can be found in supplement S1. The 5 secondary analysis studies were excluded from data synthesis of the characteristics of ABT and types of ABT across health care settings to avoid duplication in reporting. In addition to the 5 secondary analysis studies, the 2 protocol studies were also excluded from the synthesis of population data because of lack of information. Several team meetings and 2 stakeholder meetings were held to discuss data synthesis plans and key findings.

Results

Selection of sources of evidence

Figure 1 presents the PRISMA-ScR flow diagram of the search selection process. The initial search returned 2306 records. An additional 74 articles were identified for screening through scanning of the reference lists of review papers saved from the initial search. After duplicate removal and title and abstract

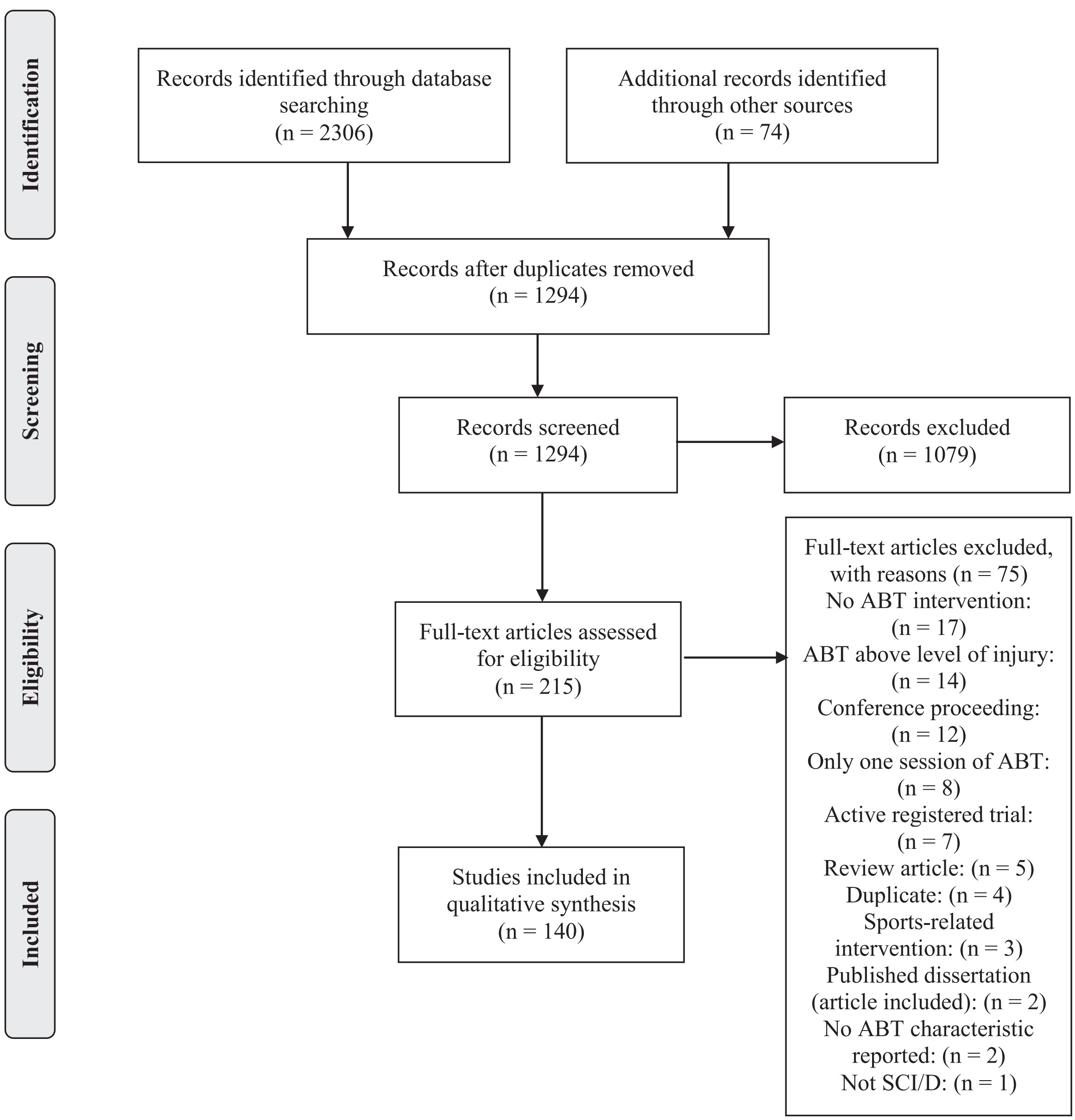

Fig 1 PRISMA-ScR flow diagram of the search selection process.

screening, 215 articles underwent full-text screening and 140 articles were selected for inclusion in this review.

Critical appraisal

The modified Downs and Black checklist was used to appraise 137 of 140 articles (see supplement table S2, available online only at http://www.archives-pmr.org/). Summary scores ranged from 8 to 24, with 22 (16.1%) articles having good methodological quality (score >19), 110 (80.3%) articles having moderate quality (scores 11-19), and 5 (3.6%) articles considered to have poor methodological quality (score <11). The 3 remaining articles included 2 protocol papers[45,46] and 1 qualitative paper[47] with the latter being appraised by the MMAT. Overall, the qualitative study had good methodological quality[45] (see supplement table S3, available online only at http://www.archives-pmr.org/).

Characteristics of sources of evidence

Included articles were published from 1986 to 2020. Most included articles (n=100, 71.4%) emerged from North America, with 80% of them arising from the Unites States. Six articles were multi-site collaborations involving 2 or more countries.[48-53] Study designs were predominantly within-subject repeated-measures (n=60, 42.9%) and randomized controlled trials (n=36, 25.7%), which included 5 secondary analyses and 2 protocol papers.[45,46,54-58] There were also a considerable number of case reports (n=18, 12.9%) and case series (n=15, 10.7%).

Characteristics of ABT

Population

Synthesized data on participant demographic and injury characteristics are presented in supplement table S4, available online only at http://www.archives-pmr.org/. A total of 2649 individuals living with SCI/D participated in the included studies, each of which ranged in sample size from 1 to 337 participants. Participant ages across studies ranged from 16 to 78 years. The mean age of participants for all non-case studies ranged from 19.2 to 62 years. Time post-injury ranged from 1 week to 53 years with a mean range of 3 weeks to 23.8 years post-injury. The most poorly reported injury characteristic was cause of injury with nearly half (n=64, 48.1%) of included articles not reporting this information. Of the studies that reported on the cause of injury, 25 (18.8%) included participants with both traumatic and non-traumatic injuries and 44 (33.1%) studies included only participants with traumatic injuries. No studies reported solely on individuals with non-traumatic injuries.

Comparison of ABT between individuals living with tetraplegia and paraplegia. A secondary review question looked at comparisons of ABT practice for people living with tetraplegia and paraplegia. Eighty-one (60.9%) studies included both individuals with tetraplegia and paraplegia. There were some differences in the type of ABT exercises provided to individuals with tetraplegia compared to individuals with paraplegia, which mainly related to an emphasis on upper extremity exercises for the former group. Thirty-five studies (26.3%) reported exclusively on individuals with tetraplegia. The most common types of exercises reported in this group included all types of electrical stimulation in combination with an ABT exercise (n=20), muscle strengthening (upper extremity n=11, lower extremity n=6), treadmill training (motorized n=11, robotic n=1, aquatic n=2), and task-specific movement practice (upper extremity n=11, lower extremity n=2).

Eleven studies (8.3%) reported exclusively on individuals with paraplegia (thoracic n=8, lumbar n=3). Individuals with thoracic level injuries participated in muscle strengthening (lower extremity n=4, upper extremity n=2), transcutaneous electrical stimulation (n=6), and ergometer training (lower extremity n=4, upper extremity n=1). Studies of participants with lumbar injuries were multi-modal case studies (3 to 7 types of ABT exercises) that included motorized treadmill training and muscle strengthening (both upper and lower extremity n=1, unspecified n=2).

Comparison of ABT between sexes and genders. A secondary review question explored differences between sexes and genders in ABT practice. Approximately 80% of participants in this review were male. Two-thirds of studies (n=89, 66.9%) included both men and women. Two studies describing body-weight supported treadmill training compared outcomes by sex.[59,60] Almost one-third of included studies (n=36, 27.1%) reported on only men, while only 2 studies (1.5%) reported on only women. Six studies (4.5%) did not report data on sex and none of the included studies reported on gender.

Concept

ABT study interventions

Seventy-three studies (54.1%) reported single modality interventions, 25 studies (18.5%) reported dual modality interventions and 42 studies (31.1%) reported multi-modal interventions of 3 or more types of ABT exercises. Five studies included more than one intervention arm with differing modalities.[59,61-64] For example, Hubscher et al reported locomoter training (single modality) for one intervention arm and locomotor and stand training for the other intervention arm (dual modality).[59] Treadmill training was the most commonly reported single modality intervention (n=36, 49.3%) followed by ergometer training (n=17, 23.3%). The most common dual modality intervention reported was treadmill training and overground walking (n=7, 28%) followed by muscle strengthening and ergometer training (n=5, 20%). Multi-modal interventions varied, ranging from 3 to 11 different types of ABT exercises that participants engaged in based on their level of function and progression through the program.

Analysis based on the region of the body targeted found most included studies described interventions targeting the whole body (n=96, 71.1%). This included ABT exercises such as treadmill training, overground walking, and load-bearing in standing. Eighteen studies (13.3%) reported interventions targeting the upper extremity only and 21 studies (15.6%) included interventions targeting only the lower extremities. Upper extremity ABT exercises were predominantly task-specific movement and muscle-strengthening exercises (n=11 each). Ergometer training was the most commonly reported type of lower extremity ABT exercise (n=16).

Table 3 Types and sub-types of ABT exercises

Type of ABT Exercise (No. of Studies)	ABT Exercise Sub-types (No. of Studies)*	
Treadmill training (80)*	Motorized treadmill training (65)	Motorized treadmill training (50)
		With transcutaneous stimulation (10)
		With epidural stimulation (4)
		With transcranial stimulation (1)
	Robotic treadmill training (20)	Robotic treadmill training (18)
		With transcutaneous stimulation (1)
		With transcranial stimulation (1)
	Aquatic treadmill training (3)	Aquatic treadmill training (3)
Muscle strengthening (49)*	Upper extremity muscle strengthening (15)	Upper extremity muscle strengthening (4)
		With transcutaneous stimulation (9)
		With virtual reality (2)
	Lower extremity muscle strengthening (19)	Lower extremity muscle strengthening (8)
		With transcutaneous stimulation (11)
	Upper & lower extremity muscle strengthening (9)	Upper & lower extremity muscle strengthening (8)
		With transcutaneous stimulation (1)
	Unspecified muscle strengthening (10)	Unspecified muscle strengthening (7)
		With transcutaneous stimulation (3)
Overground walking (44)*		Overground walking (39)
		With transcutaneous stimulation (4)
		With epidural stimulation (1)
		With transcranial stimulation (1)
Ergometer training (34)*	Arm ergometer training (11)	Arm ergometer training (10)
		With transcutaneous stimulation (1)
	Leg ergometer training (32)	Leg ergometer training (6)
		With transcutaneous stimulation (26)
	Arm & leg ergometer training (2)	With transcutaneous stimulation (1)
		With transcutaneous stimulation & virtual reality (1)
Load bearing exercises (25)*	Tilt table/standing (25)	Tilt table/standing (20)
		With transcutaneous stimulation (1)
		With epidural stimulation (4)
	Tall kneeling (6)	Tall kneeling (6)
	Crawling (1)	Crawling (1)
	Quadruped (5)	Quadruped (5)
Balance training (22)*	Standing balance training (18)	Standing balance training (15)
		With transcutaneous stimulation (1)
		With epidural stimulation (2)
	Seated balance training (3)	Seated balance training (3)
	Unspecified balance training (4)	Unspecified balance training (4)
Task-specific movements (19)*	Upper extremity task-specific movements (eg, grasp, pinch) (16)	Upper extremity task specific movements (5)
		With virtual reality (2)
		With transcutaneous stimulation (7)
		With transcranial stimulation (1)
		With transcutaneous stimulation & virtual reality (1)
	Lower extremity task specific movements (eg, ball maneuver) (5)	Lower extremity task-specific movements (4)
		With virtual reality (1)
	Unspecified task-specific movements (1)	With virtual reality (1)
Transfer training (eg, seated transfer or sit to stand) (11)		Transfer training (11)
Stair training (8)		Stair training (8)
Vibration training (6)		Whole body in standing (3)
		Multiple body parts/positions (1)
		Unspecified vibration training (2)

(continued)

Table 3 (*Continued*)

Type of ABT Exercise (No. of Studies)	ABT Exercise Sub-types (No. of Studies)*	
Unspecified cardiovascular activities (5)		Unspecified cardiovascular activities (5)
Aquatic exercises (3)		Aquatic exercises (3)
Body-weight supported elliptical training (3)		Body-weight supported elliptical training (3)
Rowing ergometer (3)		Rowing ergometer (1)
		With transcutaneous stimulation (2)
Cross trainer (1)		Cross trainer (1)
Plyometrics (1)		Plyometrics (1)
Additions to ABT Exercises (No. of Studies)		
Electrical stimulation (67)*	Transcutaneous stimulation (80)	With treadmill training (11)
		With muscle strengthening (24)
		With overground walking (4)
		With ergometer training (29)
		With load bearing in standing (1)
		With balance training (1)
		With upper extremity task-specific movements (8)
		With rowing ergometer (2)
	Epidural stimulation (11)	With treadmill training (4)
		With overground walking (1)
		With load bearing in standing (4)
		With balance training (2)
	Transcranial stimulation (4)	With treadmill training (2)
		With overground walking (1)
		With upper extremity task-specific movements (1)
Virtual reality (8)		Arm & leg ergometer training + transcutaneous stimulation (1)
		With upper extremity muscle strengthening (2)
		With upper extremity task-specific movements (2)
		With upper extremity task-specific movements + transcutaneous stimulation (1)
		With lower extremity task-specific movements (1)
		With unspecified task-specific movements (1)

* Some studies describe multi-modal interventions and/or multi-arm interventions that include different types and/or sub-types of ABT exercises. Therefore, the number of studies reported for sub-types of ABT exercises may exceed the number of studies reported for type of ABT exercise within the same category. Ex. Field-Fote and Roach conducted a randomized controlled trial comparing changes in walking speed and distance between 4 locomotor training approaches: motorized treadmill training, motorized treadmill training with transcutaneous stimulation, robotic treadmill training, and overground walking with transcutaneous stimulation.[65]

Types of ABT exercises

Table 3 presents the types and sub-types of ABT exercises reported in this review. Overall, 16 main types of ABT exercises were reported across all studies. The 3 most common types of ABT exercises were treadmill training, muscle strengthening, and overground walking, which were reported in 80, 49, and 44 studies, respectively. Muscle strengthening includes weight and resistance training as well as external facilitation combined with active participation. Plyometrics and cross-training were each reported in only one study. Electrical stimulation and virtual reality were each used in combination with another type of ABT exercise (eg, muscle strengthening with virtual reality[66]). Several of the 16 main types of ABT exercises were further subdivided into more specific subtypes of ABT exercises. For example, treadmill training was subdivided into motorized or robotic (with or without electrical stimulation) and aquatic treadmill training. The 3 most commonly reported subtypes of ABT exercises were motorized treadmill training, overground walking, and leg ergometer training with transcutaneous stimulation, which were reported in 50, 39, and 26 studies, respectively.

Types of parameters

Overall, 84 types of parameters were identified across all included studies. Six of these types of parameters were general parameters describing the interventions and individual sessions (see supplement table S5, available online only at http://www.archives-pmr.org/). The 3 most common general parameters were frequency of intervention (typically reported in sessions/week) (n=123, 91.1%), duration of intervention (typically reported in weeks) (n=122, 90.4%), and duration of session (typically reported in minutes) (n=120, 88.9%).

The remaining 78 types of parameters were specific to the 16 types of ABT exercises, 3 types of electrical stimulation, and virtual reality (see supplement table S6, available online only at http://www.archives-pmr.org/). Thirty parameters (38.5%) were reported for only one type of ABT exercise (eg, cycling resistance was only reported for ergometer training). Table 4 presents the most common specific parameters for each type of ABT exercise. Motorized treadmill training, overground walking, robotic treadmill training, and balance training exercises reported the most types of specific parameters with 31, 26, 23, and 22 parameters, respectively. Cross training did not report any specific parameters.

Types of technology

A wide variety of technology, ranging from low (eg, floor mats) to high technology (eg, robotic treadmills) was reported in the included studies. Overall, there were 16 types of technology reported across all included studies (see table 5). Five types of technology were divided into subtypes (eg, motorized, robotic, and aquatic treadmills). Most types of technology were kept broad as detail reported was often sparse and difficult to quantify (eg, miscellaneous low technology). The 3 most commonly reported types of technology were motorized treadmills (n=63, 46.7%), transcutaneous electrical stimulation (n=60, 44.4%), and miscellaneous low technology (n=46, 34.1%).

Context

There were 6 settings identified across the included studies: research lab (n=76, 56.3%), outpatient rehabilitation (n=26, 19.3%), inpatient rehabilitation (n=23, 17%), home (n=12, 8.9%), community-based clinic (n=9, 6.7%), and acute care (n=2, 1.5%). Twelve articles reported more than one setting for their intervention.

Comparison of ABT across health care settings. A secondary review question explored differences in ABT in acute care, rehabilitation, and community settings. There was a great deal of similarity in the types of ABT exercises used across the various settings. The most common types of ABT exercises reported in studies conducted in an outpatient rehabilitation setting included treadmill training (n=18) and overground walking (n=13). Transcutaneous electrical stimulation was used in combination with various types of ABT exercises in 14 studies. ABT exercises in an inpatient rehabilitation center were most commonly treadmill training (n=15) and muscle strengthening (n=10). Studies conducted in a home setting mainly reported treadmill training (n=5), muscle strengthening (n=5), ergometer training (n=4), and load-bearing exercises (n=4). Electrical stimulation was also reported in 7 studies. Most studies occurring in community-based clinics were multi-modal interventions that included treadmill training and muscle strengthening (n=7 each), as well as a variety of load-bearing exercises (n=6). The studies describing ABT in an acute care setting reported treadmill training combined with transcutaneous electrical stimulation and lower extremity ergometer training combined with load-bearing in a standing position.

Discussion

This scoping review of 140 studies identified the characteristics of ABT that people living with SCI/D participate in across the continuum of care. Over 96% of the included studies had moderate to good methodological quality. The literature reported a wide range of characteristics of ABT in regard to a modality of intervention, types of ABT exercises, and their associated parameters and technology. The participant population was skewed toward men and individuals with traumatic, incomplete, tetraplegia. Research that reported on ABT in an acute care, community-based clinic or home setting was scarce.

Characteristics of ABT

Population

Although 80% of participants in this scoping review were male, this finding is in alignment with SCI population-level data.[67-69] Most studies in this review that included both male and female participants lacked a sufficient sample size for sex-based analyses (ie, approximately 50% of studies had 10 or fewer participants). Similarly, no included studies collected gender data; hence, we were unable to determine if there were any sex or gender differences in the types of ABT exercises individuals participated in. There are likely numerous reasons why sex and gender data were not adequately reported or analyzed in the included studies. For example, researchers may not expect the outcomes of ABT to differ

Table 4 Most common specific parameters for each type of ABT exercise

Type of ABT Exercise		Specific Parameters (No. of Studies, %)
Treadmill training	Motorized treadmill training	Percentage of body weight support (53, 85.5%)
		Manual assistance required (49, 79%)
		Walking speed (43, 69.4%)
	Robotic treadmill training	Percentage of body weight support (19, 95%)
		Walking speed (18, 90%)
		Guidance force (10, 50%)
	Aquatic treadmill training	Percentage of body weight support (or H_2O level/height) (3, 100%)
		Walking speed (3, 100%)
		Water temperature (3, 100%)
		Duration of set (2, 66.7%)
		Manual assistance required (2, 66.7%)
		Number of sets (2, 66.7%)
Muscle strengthening		Muscle(s) targeted (39, 79.6%)
		Number of repetitions (17, 34.7%)
		Duration of rest breaks (12, 24.5%)
		Number of sets (12, 24.5%)
Overground walking		Gait aid (18, 40.9%)
		Manual assistance required (9, 20.5%)
		Walking direction (eg, forward, backward) (9, 20.5%)
Ergometer training		Cadence (19, 55.9%)
		Cycling resistance (13, 38.2%)
		Power output (11, 32.4%)
Load bearing exercises		Standing apparatus (14, 56%)
		Manual assistance required (9, 36%)
		Percentage of body weight support (8, 32%)
Balance training		Postural stability (13, 59.1%)
		Starting position (12, 54.5%)
		Type of task (8, 36.4%)
Task specific movements		Type of task (18, 94.7%)
		Task difficulty (6, 31.6%)
		Number of repetitions (5, 26.3%)
		Number of rest breaks (5, 26.3%)
Transfer training (eg, seated transfer or sit to stand)		Starting position (10, 90.9%)
		Manual assistance required (4, 36.4%)
		Standing apparatus (4, 36.4%)
Stair training		Walking speed (5, 62.5%)
		Upper extremity support (3, 37.5%)
		Heart rate or percentage of HRmax (2, 25%)
		Rating of perceived exertion (2, 25%)
Vibration training		Vibration frequency (1, 16.7%)
Body-weight supported elliptical training		Percentage of body weight support (1, 33.3%)
		Manual assistance required (1, 33.3%)
Rowing ergometer		Duration of set (2, 66.7%)
		Heart rate or percentage of HRmax (2, 66.7%)
		Number of sets (2, 66.7%)
		Work-to-rest ratio (2, 66.7%)
Cross trainer		None reported
Plyometrics		Starting position (1, 100%)
		Load (weight) (1, 100%)
		Lower extremity participation (1, 100%)
		Number of repetitions (1, 100%)
Additions to ABT Exercise		
Electrical stimulation	Transcutaneous stimulation	Stimulation intensity (49, 81.7%)
		Stimulation frequency (45, 75%)
		Pulse width (43, 71.7%)
		Muscle(s) targeted (42, 70%)
		Electrode placement (32, 53.3%)
	Epidural spinal stimulation	Electrode placement (4, 100%)

(*continued*)

Table 4 (*Continued*)

Type of ABT Exercise		Specific Parameters (No. of Studies, %)
		Stimulation frequency (3, 75%)
		Stimulation intensity (3, 75%)
		Pulse width (2, 50%)
	Transcranial stimulation	Muscle(s) targeted (3, 100%)
		Stimulation intensity (3, 100%)
		Electrode placement (2, 66.7%)
		Size of electrode (2, 66.7%)
		Vertex (2, 66.7%)
Virtual reality		Level of immersion (7, 87.5%)
		Muscle(s) targeted (6, 75%)
		Type of task (6, 75%)
		Task difficulty (5, 62.5%)

between sexes or genders as prior research has suggested SCI/D rehabilitation outcomes do not.[70] Moreover, it may be difficult to collect gender data in a meaningful way, as it exists on a continuum and is influenced by behavioral, cultural, and psychological characteristics.[71] The lack of sex- and gender-based analyses in SCI/D research has been noted by others. A recent review article on cardiometabolic disease in SCI/D reported on the challenge of completing sex- and/or gender-based analyses.[72] Similar to our findings, sex-specific analyses were not performed as part of the review because of the small sample sizes and lack of sex-specific data reported in the original studies.[72]

Our findings also highlighted differences in the types of ABT exercises practiced by individuals with tetraplegia compared to those living with paraplegia. Not surprisingly, individuals living with tetraplegia, who identify improvements in arm function as a top rehabilitation priority,[73] engaged in ABT exercises focused on neuromuscular activation of the upper limb.

Concept

ABT study interventions, exercises, and their associated parameters. As indicated by this review, many exercises are considered ABT. To our knowledge, this review is the first to identify and categorize parameters for ABT interventions and exercises. Many parameters were identified and categorized as general to the intervention or specific to the type of ABT exercise. Several specific parameters, such as the number of sets, the number of rest breaks needed, and the amount of manual assistance required could be generalized across most types of ABT exercises. This knowledge will be useful when developing tools to track participation in ABT. Categorizing parameters according to the type of ABT exercise will benefit clinicians engaged in ABT in knowing the type of information to document, as well as researchers when designing studies in determining the type of data to collect.

Nearly 40% of parameters were reported for only one type of ABT exercise revealing the specificity and uniqueness of many parameters. Some exercises not well described in the literature (ie, vibration training) had very few documented parameters suggesting there may be unreported parameters for certain types of ABT exercises where literature was scarce. Over 15% of parameters were reported only once across all studies and types of ABT exercises, which may be the result of poor documentation and not a measure of the parameter's value or importance. A key consideration, depending on the type of technology used, is that parameters may vary within an ABT exercise, which can pose a challenge when developing methods to track ABT and deciding on which parameters to include.

Since exercise intensity is a key element of ABT practice, it was interesting that so few included studies reported on exercise intensity; for example, a measure of heart rate was reported in only 12% of studies. This finding identifies an important gap in the published ABT literature. It is increasingly recognized that the physiological mechanisms underlying neuroplasticity and motor learning are facilitated by training at higher exercise intensities.[74,75] Other metrics of training dosage (eg, frequency and duration of sessions) were commonly reported in included studies (ie, >90%); yet these metrics are not indicative of exercise intensity.[76] We suggest that exercise intensity should be considered a general parameter (supplement table S5) that is routinely documented across ABT exercises.

Types of technology. Many types of ABT exercises identified in this review involve technology, which varied both within and across the types of ABT exercises. For example, Zhou et al reported using multiple brands of ergometers in their study[77] and Esclarín-Ruz et al reported using multiple types of gait aids for overground walking.[78] This is comparable to Cheung et al who reported technology use as a way to tailor exercises and treatment programs based on a participant's level of function.[18] The technologies reported in this review also ranged from low technology, such as ramps and balls, to moderate-level technologies (eg, motorized treadmills), to high technology equipment like robotic treadmills and electrical stimulation. A qualitative study looking at clinician's use of technology in practice likewise reported utilization of low to high technology alone or in combination to achieve therapeutic goals.[19] Similar to other studies,[13,15,18] this review reported technology utilization in multiple ways as an avenue to assist (eg, body-weight supported harness for treadmill training), challenge (eg, placing obstacles in a path for a participant to walk over or around) and support

Table 5 Types of technology

Type of Technology (No. of Studies)	Sub-type (No. of Studies)
Treadmill (81)*	Motorized treadmill (63) (eg, body-weight supported treadmill training, AlterG treadmill training)
	Robotic treadmill (20)
	Aquatic treadmill (3)
Electrical Stimulation (67)	Transcutaneous stimulation (60) (eg, NMES, FES, FES garment, TENS, TMS, somatosensory, surface spinal)
	Epidural stimulation (4)
	Transcranial stimulation (3)
Miscellaneous low technology (46)† (eg, floor mat, positioning Items [ie, Velcro straps], upper extremity props [ie, ball, can, cards], lower extremity props/equipment [ie, blocks, ramps])	Miscellaneous low technology (46)
Ergometer (34)‡ (eg, arm crank, hand cycle, tricycle, stationary bike, leg cycle)	Upper extremity ergometer (10)
	Upper extremity ergometer with transcutaneous stimulation (1)
	Lower extremity ergometer (6)
	Lower extremity ergometer with transcutaneous stimulation (25)
	Upper & lower extremity ergometer with transcutaneous stimulation (2)
Gait aids§ (30) (eg, gait aids such as a walker or overhead suspension with body weight support)	Gait aids (30)
Weight machine or free weights (18)	Weight machine or free weights (18)
Standing frame or tilt table (12)	Standing frame or tilt table (12)
Stairs or stair machine (8)	Stairs or stair machine (8)
Upper extremity device (7)	Manual upper extremity device (4)
	Robotic upper extremity device (3)
Virtual gaming or interactive exercise computer game (8)	Virtual gaming or interactive exercise computer game (8)
Pool (6)	Pool (6)
Vibrating platform (6)	Vibrating platform (6)
Body-weight supported elliptical (3)	Body-weight supported elliptical (3)
Row ergometer (3)	Row ergometer (1)
	Row ergometer with transcutaneous stimulation (2)
Cross trainer (1)	Cross trainer (1)
Jump training device (1)	Jump training device (1)

* Reported 86 times across 81 studies as some study interventions were 2-arm comparison studies and 1 study used a treadmill for balance training in standing.
† Studies reporting miscellaneous low technology often included multiple items which were not properly documented so unable to provide individual counts.
‡ Reported 44 times across 34 studies as some study interventions included more than 1 type of ergometer.
§ Studies reporting gait aids often included multiple items which were not properly documented so unable to provide individual counts.

an individual during a specific exercise (eg, standing frame for load-bearing in standing). The importance of electrical stimulation as a powerful device to promote sensorimotor recovery was also supported in previous reviews.[13,15,20,28] The high use of technology, low technology (33.3%) in particular, signifies the versatility of ABT across a wide range of settings and within the financial constraints of individuals, community clinics, and hospitals.

Context

There was a paucity of studies in this review reporting on ABT in an acute care, community-based clinic and home setting. The ability to provide ABT early on post-SCI may be essential to promote optimal rehabilitation outcomes. In spite of over 35% of studies in this review reporting on ABT in a rehabilitation setting, implementing ABT in the inpatient hospital setting may prove challenging. Mounting pressures within a financially constrained health care system limit the length of stay and dosage of therapy (ie, frequency and duration of sessions, number of movement repetitions) provided to patients.[5,79] Whiteneck et al reported an average length of hospital stay of 55 days and a total of 24 hours per week of treatment across all disciplines after SCI/D.[80] This translated to 2 and 4 hours per week of ABT-related occupational and physical therapy, respectively.[81,82] Zbogar et al reported an average of 2 upper limb repetitions per session and 115 steps per session at discharge from inpatient rehabilitation after SCI/D.[83] In comparison to current practice, the study by Holleran et al in this review reported an average of 2222±653 steps per session, which led to moderate improvements in gait function.[84] Strategies to reduce barriers to implementation of ABT within the acute care and rehabilitation settings should be a focus at optimizing rehabilitation outcomes. In addition, although few studies in this review reported on ABT in the community and home, individuals living with SCI describe participating in ABT for years as part of their ongoing rehabilitation and physical fitness.[17] Therefore, there is a need for tailored community and home-based ABT programs.

Implications of review findings

The findings from this review can be used in a number of ways. The types and characteristics of ABT can inform the development of a tool to document and track participation in an ABT session or program. A tool of this nature would enable the collection of valuable information to determine optimal dosage and develop guidelines for delivery of ABT across injury profiles and care settings.

The findings may also assist researchers, during the planning of future studies, with identifying the specific parameters to track for a specific intervention or type of ABT exercise. Finally, clinicians in both hospital and community-based settings may find the scoping review results a useful guide to assist in determining the exact parameters to track for specific types of ABT exercises with their patients/clients in practice.

Limitations

Historically, ABT has evolved from and is rooted in literature describing gait training and electrical stimulation.[13-15,85] Consequently, developing a search strategy posed challenging as many study interventions were described by their targeted exercise as opposed to being labeled as ABT. To reduce selection bias, we avoided including these interventions as specific search terms. In addition, we avoided general terms for exercise to limit the number of irrelevant records retrieved as experienced in a previous review.[15] As a result, we kept the search terms specific to ABT and related terms which led to a much smaller volume of retrieved records. To ensure we did not miss any key studies, we searched the references of included studies as well as ABT review papers, which resulted in a much larger collection of articles retrieved from other sources than normally expected. The search excluded books and gray literature, which may have led to unreported or under-reported ABT exercises and their corresponding parameters. Nevertheless, with the volume of studies included in this review, we feel confident that our aims were suitably addressed.

Future research directions

As none of the studies reported on gender and only 2 studies that included both men and women compared outcomes between the sexes, further research on sex and gender differences related to ABT practice and participation is warranted. An ABT tracking tool may facilitate the identification of sex and gender differences related to dosage, exercise intensity, and types of ABT exercises. In addition, because a large portion of studies in this review included individuals living with traumatic, incomplete injuries and tetraplegia, research focused on participation in ABT of individuals with non-traumatic, complete injuries and paraplegia is recommended for further study. Although beyond the scope of this study, future research should consider exploring additional participant characteristics that may influence participation in ABT, such as age, time since injury, and severity of injury. As a next step toward item generation and tool development, interviews with relevant stakeholder groups to identify characteristics of ABT across the continuum of care following SCI/D is encouraged.

Conclusions

This scoping review provided an understanding of the characteristics of ABT across the continuum of care after SCI/D. The characteristics of ABT were diverse and multi-faceted, varying by modality of intervention, types of ABT exercises, and their associated parameters and technology. The characteristics and types of ABT identified in this scoping review may be used to develop tools capable of effectively documenting the details of participation in an ABT session or program.

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Appendix 1. Search Strategy for Medline

Number	Searches
1	spinal cord diseases/
2	epidural abscess/
3	myelitis/
4	myelitis, transverse/
5	Pneumorrhachis/
6	spinal cord compression/
7	exp spinal cord injuries/
8	exp spinal cord neoplasms/
9	exp spinal cord vascular diseases/
10	syringomyelia/
11	tabes dorsalis/
12	exp Paraplegia/
13	Quadriplegia/
14	(spinal cord adj3 (injur* or disease* or disorder* or compress* or neoplasm* or tumor* or tumour* or trauma* or non-trauma* or laceral* or lesion* or contusion* or inflammat* or ischemi* or pinching)).tw,kw.
15	((spinal cord or SCI) adj3 (acute* or sub-acute* or chronic*)).tw,kw.
16	(paraplegi* or quadriplegi* or tetraplegi* or post-SCI).tw,kw.
17	(myelitis or myelopath* or myelitides or hematomyeli* or pneumorrhachi* or pneumorhachi* or neuromyelopath*).tw,kw.
18	(abscess adj3 (spinal or epidural or extradural)).tw,kw.
19	(syringomyel* or hydrosyringomyel* or myclosyringos* or myelosyphilis or meningomyeliti* or myelosyringos* or syringohydromyelia*).tw,kw.
20	(tabes adj3 (spinalis or dorsalis)).tw,kw.
21	(ataxia adj3 locomotor).tw,kw.
22	or/1-21
23	[Intervention ABT]
24	exp Exercise Therapy/ and (activity-based or activity based).mp,kw.
25	((activity-based or activity based or restorative* or repetiti*) adj4 (therap* or training or rehab* or locomotor*)).mp,kw.
26	(ABT* or ABRT* or AB-LT*).tw,kw.
27	((intens* or activity based or activity-based) adj4 (therap* or PT or exercise* or kinesitherap* or kinesiotherap*)).tw,kw.
28	(locomotor and (activity-based or activity based or repetiti* or task-specific or task specific)).tw,kw.
29	(repetiti* adj4 (motor activit* or task-specific or task specific)).tw,kw.
30	Or/24-29
31	22 and 30

References

1. Hitzig SL, Tonack M, Campbell KA, et al. Secondary health complications in an aging Canadian spinal cord injury sample. Am J Phys Med Rehabil 2008;87:545-55.
2. Hitzig SL, Campbell KA, Mcgillivray CF, Boschen KA, Craven BC. Understanding age effects associated with changes in secondary health conditions in a Canadian spinal cord injury cohort. Spinal Cord 2010;48:330-5.
3. Sun X, Jones Z, Chen X, Zhou L, So K, Ren Y. Multiple organ dysfunction and systemic inflammation after spinal cord injury: a complex relationship. J Neuroinflammation 2016;13:260.
4. Stillman MD, Barber J, Burns S, Williams S, Hoffman JM. Complications of spinal cord injury over the first year after discharge from inpatient rehabilitation. Arch Phys Med Rehabil 2017;98:1800-5.
5. Behrman AL, Harkema SJ. Physical rehabilitation as an agent for recovery after spinal cord injury. Phys Med Rehabil Clin N Am 2007;18:183-202.
6. Casperen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Public Health Rep 1985;100:126-31.
7. Martin Ginis KA, van der Scheer JW, Latimer-Cheung AE, et al. Evidence-based scientific exercise guidelines for adults with spinal cord injury: an update and a new guideline. Spinal Cord 2018;56:308-21.
8. Pink B. Defining sport and physical activity: a conceptual model. Canberra: Australian Bureau of Statistics; 2008.
9. Tawashy AE, Eng JJ, Lin KH, Tang PF, Hung C. Physical activity is related to lower levels of pain, fatigue and depression in individuals with spinal-cord injury: a correlational study. Spinal Cord 2009;47:301-6.
10. van der Scheer JW, Martin Ginis KA, Ditor DS, et al. Effects of exercise on fitness and health of adults with spinal cord injury: a systematic review. Neurology 2017;89:736-45.
11. Nightingale TE, Rouse PC, Walhin JP, Thompson D, Bilzon JLJ. Home-based exercise enhances health-related quality of life in persons with spinal cord injury: a randomized controlled trial. Arch Phys Med Rehabil 2018;99. 1998-2006.e1.
12. Jones ML, Harness E, Denison P, Tefertiller C, Evans N, Larson CA. Activity-based therapies in spinal cord injury: clinical focus and empirical evidence in three independent programs. Top Spinal Cord Inj Rehabil 2012;18:34-42.

13. Dolbow DR, Gorgey AS, Recio AC, et al. Activity-based restorative therapies after spinal cord injury: inter-institutional conceptions and perceptions. Aging Dis 2015;6:254–61.
14. Behrman AL, Ardolino EM, Harkema SJ. Activity-based therapy: from basic science to clinical application for recovery after spinal cord injury. JNPT 2017;41:S39–45.
15. Quel de Oliveira C, Refshauge K, Middleton J, de Jong L, Davis GM. Effects of activity-based therapy interventions on mobility, independence, and quality of life for people with spinal cord injuries: a systematic review and meta-analysis. J Neurotrauma 2017;34:1726–43.
16. Angeli CA, Boakye M, Morton RA, et al. Recovery of over-ground walking after chronic motor complete spinal cord injury. N Engl J Med 2018;379:1244–50.
17. Swaffield E, Cheung L, Khalili A, et al. Perspectives of people living with a spinal cord injury on activity-based therapy. Disabil Rehabil 2022;44:3632–40.
18. Cheung L, Musselman KE, Kaiser A, et al. Activity-based therapy in the community for individuals living with spinal cord injury or disease: qualitative interviews with clinicians. Disabil Rehabil 2022;44:4821–30.
19. Jervis Rademeyer H, Gauthier C, Zariffa J, et al. Using activity-based therapy for individuals with spinal cord injury or disease: interviews with physical and occupational therapists in rehabilitation hospitals. J Spinal Cord Med 2022 Mar 29. [Epub ahead of print].
20. Sadowsky CL, McDonald JW. Activity-based restorative therapies: concepts and applications in spinal cord injury-related neurorehabilitation. Dev Disabil Res Rev 2009;15:112–6.
21. Quel de Oliveira C, Middleton JW, Refshauge K, Davis GM. Activity-based therapy in a community setting for independence, mobility, and sitting balance for people with spinal cord injuries. J Cent Nerv Syst Dis 2019;11:1–9.
22. Musselman KE, Walden K, Noonan VK, et al. Development of priorities for a Canadian strategy to advance activity-based therapies after spinal cord injury or disease. Spinal Cord 2021;59:874–84.
23. Guyatt GH, Bombardier C, Tugwell PX. Measuring disease-specific quality of life in clinical trials. CMAJ 1986;134:889–95.
24. Clark LA, Watson D. Constructing validity: basic issues in objective scale development. Psychol Assess 1995;7:309–19.
25. Arksey H, O'Malley L. Scoping studies: towards a methodological framework. Int J Soc Res Methodol 2005;8:19–32.
26. Peters MD, Godfrey CM, Khalil H, McInerney P, Parker D, Soares CB. Guidance for conducting systematic scoping reviews. Int J Evid Based Healthc 2015;13:141–6.
27. Dromerick AW, Lum PS, Hidler J. Activity-based therapies. NeuroRX 2006;3:428–38.
28. Backus D. Activity-based interventions for the upper extremity in spinal cord injury. Top Spinal Cord Inj Rehabil 2008;13:1–9.
29. Thielen CC, Marino RJ, Duff S, Kaplan G, Mulcahey MJ. Activity-based rehabilitation interventions of the neurologically impaired upper extremity: description of a scoping review protocol. Top Spinal Cord Inj Rehabil 2018;24:288–94.
30. Grampurohit N, Marino R, Bell A, et al. A scoping review of activity-based therapy for the neurologically impaired upper extremity. Arch Phys Med Rehabil 2019;100:e213.
31. Peters MDJ, Godfrey C, McInerney P, et al. Chapter 11: Scoping Reviews (2020 version). In: Aromataris E, Munn Z, eds. Joanna Briggs Institute reviewer's manual. Joanna Briggs Institute; South Australia, 2020. Available at: https://reviewersmanual.joannabriggs.org/. Accessed September 5, 2022
32. Kaiser A, Chan K, Musselman K. Activity-based therapy interventions for people living with spinal cord injury or disease across the continuum of care: a scoping review protocol. Registered on open science framework on March 11, 2020. Available at: https://osf. io/jhcpd
33. Kaiser A, Chan K, Pakosh M, Musselman KE. Characteristics of activity-based therapy interventions for people living with spinal cord injury or disease across the continuum of care: a scoping review protocol. BMJ Open 2020;10:e040014.
34. Tricco AC, Lillie E, Zarin W, et al. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. Ann Intern Med 2018;169:467–73.
35. Chalabaev A, Sarrazin P, Fontayne P, Boiché J, Clément-Guillotin C. The influence of sex stereotypes and gender roles on participation and performance in sport and exercise: review and future directions. Psychol Sport Exerc 2013;14:136–44.
36. Sipski ML, Jackson AB, Gómez-Marín O, Estores I, Stein A. Effects of gender on neurologic and functional recovery after spinal cord injury. Arch Phys Med Rehabil 2004;85:1826–36.
37. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. J Epidemiol Community Health 1998;52:377–84.
38. Saunders LD, Soomro GM, Buckingham J, Jamtvedt G, Raina P. Assessing the methodological quality of nonrandomized intervention studies. West J Nurs Res 2003;25:223–37.
39. Eng JJ, Teasell R, Miller WC, et al. Spinal cord injury rehabilitation evidence: methods of the SCIRE systematic review. Top Spinal Cord Inj Rehabil 2007;13:1–10.
40. Methajarunon P, Eitivipart C, Diver CJ, Foongchomcheay A. Systematic review of published studies on aquatic exercise for balance in patients with multiple sclerosis, Parkinson's disease, and hemiplegia. Hong Kong Physiother J 2016;35:12–20.
41. Hong QN, Pluye P, Fàbregues S, et al., Mixed methods appraisal tool (MMAT), version. 2018. Canadian Intellectual Property Office, Industry Canada; Canada: 2018.
42. National Collaborating Centre for Methods and Tools. Appraising qualitative, quantitative and mixed methods studies included in mixed studies reviews: the MMAT. Hamilton, ON: McMaster University; 2015.
43. Pluye P, Gagnon MP, Griffiths F, Johnson-Lafleur J. A scoring system for appraising mixed methods research, and concomitantly appraising qualitative, quantitative and mixed methods primary studies in mixed studies reviews. Int J Nurs Stud 2009;46:529–46.
44. Pace R, Pluye P, Bartlett G, et al. Testing the reliability and efficiency of the pilot Mixed Methods Appraisal Tool (MMAT) for systematic mixed studies review. Int J Nurs Stud 2012;49:47–53.
45. Bedi PK, Arumugam N, Chhabra HS. Effectiveness of activity-based therapy in comparison with surface spinal stimulation in people with traumatic incomplete spinal cord injury for activation of central pattern generator for locomotion: study protocol for a 24-week randomized controlled trial. Asian Spine J 2018;12:503–10.
46. Unger J, Chan K, Scovil CY, et al. Intensive balance training for adults with incomplete spinal cord injuries: Protocol for an assessor-blinded randomized clinical trial. Physical Therapy 2019;99:420–7.
47. Singh H, Shah M, Flett HM, Craven BC, Verrier MC, Musselman KE. Perspectives of individuals with sub-acute spinal cord injury after personalized adapted locomotor training. Disabil Rehabil 2018;40:820–8.
48. Wirz M, Zemon DH, Rupp R, et al. Effectiveness of automated locomotor training in patients with chronic incomplete spinal cord injury: a multicenter trial. Arch Phys Med Rehabil 2005;86:672–80.
49. Dobkin B, Barbeau H, Deforge D, et al. The evolution of walking-related outcomes over the first 12 weeks of rehabilitation for incomplete traumatic spinal cord injury: the multicenter randomized spinal cord injury locomotor trial. Neurorehabil Neural Repair 2007;21:25–35.
50. Frotzler A, Coupaud S, Perret C, et al. High-volume FES-cycling partially reverses bone loss in people with chronic spinal cord injury. Bone 2008;43:169–76.

51. Hasnan N, Engkasan JP, Husain R, Davis GM. High-intensity virtual-reality arm plus FES-leg interval training in individuals with spinal cord injury. Biomed Tech 2013;58:S1-2.
52. Harvey LA, Dunlop SA, Churilov L, Galea MP. Spinal Cord Injury Physical Activity (SCIPA) Hands On Trial Collaborators. Early intensive hand rehabilitation is not more effective than usual care plus one-to-one hand therapy in people with sub-acute spinal cord injury ('Hands On'): a randomised trial. J Physiother 2016;62:88-95.
53. Wirz M, Mach O, Maier D, et al. Effectiveness of automated locomotor training in patients with acute incomplete spinal cord injury: a randomized, controlled, multicenter trial. J Neurotrauma 2017;34:1891-6.
54. Guest RS, Klose KJ, Needham-Shropshire BM, Jacobs PL. Evaluation of a training program for persons with SCI paraplegia using the Parastep 1 ambulation system: part 4. Effect on physical self-concept and depression. Arch Phys Med Rehabil 1997;78:804-7.
55. Nash MS, Jacobs PL, Montalvo BM, Klose J, Guest RS, Needham-Shropshire BM. Evaluation of a training program for persons with SCI paraplegia using the Parastep l ambulation system: part 5. Lower extremity blood flow and hyperemic responses to occlusion are augmented by ambulation training. Arch Phys Med Rehabil 1997;78:808-14.
56. Needham-Shropshire BM, Broton JG, Klose KJ, Lebwohl N, Guest RS, Jacobs PL. Evaluation of a training program for persons with SCI paraplegia using the Parastep 1 ambulation system: part 3. Lack of effect on bone mineral density. Arch Phys Med Rehabil 1997;78:799-803.
57. Jones ML, Evans N, Tefertiller C, et al. Activity-based therapy for recovery of walking in chronic spinal cord injury: results from a secondary analysis to determine responsiveness to therapy. Arch Phys Med Rehabil 2014;95:2247-52.
58. Gerber CS. Does participation in a multi-modal activity-based program impact functional recovery and quality of life in adults with spinal cord injury? San Diego, California: University of San Diego; 2014.
59. Hubscher CH, Herrity AN, Williams CS, et al. Improvements in bladder, bowel and sexual outcomes following task-specific locomotor training in human spinal cord injury. PLoS One 2018;13:e0190998.
60. Morrison SA, Lorenz D, Eskay CP, Forrest GF, Basso M. Longitudinal recovery and reduced costs after 120 sessions of locomotor training for motor incomplete spinal cord injury. Arch Phys Med Rehabil 2018;99:555-62.
61. Needham-Shropshire BM, Broton JG, Cameron TL, Klose KJ. Improved motor function in tetraplegics following neuromuscular stimulation-assisted arm ergometry. J Spinal Cord Med 1997;20:49-55.
62. Laskin JJ. Physiological adaptations to concurrent muscular strength and aerobic endurance training in functionally active adults with a physical disability. Edmonton, AB, Canada: University of Alberta; 2001.
63. Labruyère R, van Hedel HJ. Strength training versus robot-assisted gait training after incomplete spinal cord injury: a randomized pilot study in patients depending on walking assistance. J Neuroeng Rehabil 2014;11:4.
64. Momeni K, Ramanujam A, Garbarini EL, Forrest GF. Multi-muscle electrical stimulation and stand training: effects on standing. J Spinal Cord Med 2019;42:378-86.
65. Field-Fote EC, Roach KE. Influence of a locomotor training approach on walking speed and distance in people with chronic spinal cord injury: a randomized clinical trial. Phys Ther 2011;91:48-60.
66. Kadivar Z, Sullivan JL, Yozbatiran N. Robotic training and kinematic analysis of arm and hand after incomplete spinal cord injury: a case study. 2011 IEEE Int Conf Rehabil Robot 2011: 1-6.
67. Praxis Spinal Cord Institute. Rick Hansen SCI Registry Community Report. Vancouver, BC: Praxis; 2019.
68. National Spinal Cord Injury Statistical Center. Spinal cord injury facts and figures at a glance. Birmingham, AL, USA; 2020.
69. Wyndaele M, Wyndaele J-J. Incidence, prevalence and epidemiology of spinal cord injury: what learns a worldwide literature survey? Spinal Cord 2006;44:523-9.
70. Scivoletto G, Morganti B, Molinari M. Sex-related differences of rehabilitation outcomes of spinal cord lesion patients. Clin Rehabil 2004;18:709-13.
71. Miller VM. Why are sex and gender important to basic physiology and translational and individualized medicine? Am J Physiol Heart Circ Physiol 2014;306:H781-8.
72. Raguindin PR, Muka T, Glisic M. Sex and gender gap in spinal cord injury research: focus on cardiometabolic diseases. A mini review. Maturitas 2021;147:14-8.
73. Anderson KD. Targeting recovery: priorities of the spinal cord-injured population. J Neurotrauma 2004;21:1371-83.
74. Leech KA, Hornby TG. High-intensity locomotor exercise increases brain-derived neurotrophic factor in individuals with incomplete spinal cord injury. J Neurotrauma 2017;34:1240-8.
75. Wanner P, Cheng F, Steib S. Effects of acute cardiovascular exercise on motor memory encoding and consolidation: a systematic review with meta-analysis. Neurosci Biobehav Rev 2020;116:265-81.
76. Hicks AL. Locomotor training in people with spinal cord injury: is this exercise? Spinal Cord 2021;59:9-16.
77. Zhou R, Alvarado L, Ogilvie R, Chong SL, Shaw O, Mushahwar VK. Non-gait-specific intervention for the rehabilitation of walking after SCI: role of the arms. J Neurophysiol 2018;119:2194-211.
78. Esclarín-Ruz A, Alcobendas-Maestro M, Casado-Lopez R, et al. A comparison of robotic walking therapy and conventional walking therapy in individuals with upper versus lower motor neuron lesions: a randomized controlled trial. Arch Phys Med Rehabil 2014;95:1023-31.
79. Burns AS, Santos A, Cheng CL, et al. Understanding length of stay after spinal cord injury: Insights and limitations from the access to care and timing project. J Neurotrauma 2017;34:2910-6.
80. Whiteneck G, Gassaway J, Dijkers M, et al. Inpatient treatment time across disciplines in spinal cord injury rehabilitation. J Spinal Cord Med 2011;34:133-48.
81. Foy T, Perritt G, Thimmaiah D, et al. Occupational therapy treatment time during inpatient spinal cord injury rehabilitation. J Spinal Cord Med 2011;34:162-75.
82. Taylor-Schroeder S, LaBarbera J, McDowell S, et al. The SCIRehab project: treatment time spent in SCI rehabilitation. Physical therapy treatment time during inpatient spinal cord injury rehabilitation. J Spinal Cord Med 2011;34:149-61.
83. Zbogar D, Eng JJ, Miller WC, Krassioukov AV, Verrier MC. Movement repetitions in physical and occupational therapy during spinal cord injury rehabilitation. Spinal Cord 2017;55:172-9.
84. Holleran CL, Hennessey PW, Leddy AL, et al. High-intensity variable stepping training in patients with motor incomplete spinal cord injury: a case series. J Neurol Phys Ther 2018;42:94-101.
85. Harness ET, Yozbatiran N, Cramer SC. Effects of intense exercise in chronic spinal cord injury. Spinal Cord 2008;46:733-7.