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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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.
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 neuro-muscular system below the level of lesion with the goal of retraining the nervous system to recover a specific motor task.”9 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/). 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. 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 framework31 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. | • Animal studies. |
| • All neurologic levels of injury (ie, cervical, thoracic and lumbar segments). | • Literature reporting on individuals less than 16 years of age for who the approach to rehabilitation would likely be pediatric focused (eg, play based). |
| • All degrees of injury severity (ie, American Spinal Injury Association Impairment Scale (AIS) classification of A, B, C, or D). | • Studies focused on congenital causes of spinal damage (eg, spina bifida). |
| • Individuals with SCI/D may be at any stage in their recovery; that is, acute, sub-acute or chronic stages. | • Studies reporting only one session of ABT. |
| • 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.” | • Studies reporting on exercises targeting muscles above the level of injury only. |
| • 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 | • 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. 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). 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. 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”. The Downs and Black checklist has high internal consistency, good face and criterion validity, and good test-retest and inter-rater reliability. 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). 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. The MMAT demonstrates good validity and reliability. 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. 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...
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 and 1 qualitative paper with the latter being appraised by the MMAT. Overall, the qualitative study had good methodological quality (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 United States. Six articles were multi-site collaborations involving 2 or more countries. 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. 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. 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. For example, Hubscher et al reported locomotor training (single modality) for one intervention arm and locomotor and stand training for the other intervention arm (dual modality). 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).
| Type of ABT Exercise (No. of Studies) | ABT Exercise Sub-types (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)    |
|                                     | 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)    |
|                                     | Lower extremity muscle strengthening (19)| Lower extremity muscle strengthening (8) |
|                                     |                                        | With virtual reality (2)              |
|                                     | Upper & lower extremity muscle strengthening (9) | Upper & lower extremity muscle strengthening (8) |
|                                     |                                        | With transcutaneous stimulation (11)   |
|                                     | 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)          |
| 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)       | Arm & leg ergometer training (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)    |
|                                     | 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)      |
|                                     | Lower extremity task-specific movements (eg, ball maneuver) (5) | Lower extremity task-specific movements (4) |
|                                     |                                        | With virtual reality (1)              |
| Transfer training (eg, seated transfer or sit to stand) (11) | Unspecified task-specific movements (1) | 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) |
| Cross trainer (1) | Cross trainer (1) |
| Plyometrics (1) | Plyometrics (1) |
| **Additions to ABT Exercises (No. of Studies)** | **Transcutaneous stimulation (80)** |
| Electrical stimulation (67)* | 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) |
| | 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) |
| Virtual reality (8) | 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 reality66). 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%).

Comparison of ABT across healthcare 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.
| 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 H2O 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%)                                                                     |
| **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%)                                                                     |
| **Balance training**                  |                                                                                                          |
|                                      | Postural stability (13, 59.1%)                                                                          |
|                                      | Starting position (12, 54.5%)                                                                          |
| **Task specific movements**           |                                                                                                          |
|                                      | Type of task (8, 36.4%)                                                                                 |
|                                      | 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%)                                                            |
| **Rowing ergometer**                  |                                                                                                          |
|                                      | Duration of set (2, 66.7%)                                                                             |
|                                      | Heart rate or percentage of HRmax (2, 66.7%)                                                            |
|                                      | Number of sets (2, 66.7%)                                                                              |
| **Cross trainer**                     |                                                                                                          |
|                                      | None reported                                                                                            |
| **Plyometrics**                       |                                                                                                          |
|                                      | Starting position (1, 100%)                                                                            |
|                                      | Load (weight) (1, 100%)                                                                                |
|                                      | Lower extremity participation (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%)                                                                         |
| **Additions to ABT Exercise**         |                                                                                                          |
| **Epidural spinal stimulation**       | Electrode placement (4, 100%)                                                                          |

(continued)
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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 study77 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

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

Table 4 (Continued)
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

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,

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)  | Upper extremity ergometer (10) |
| (eg, floor mat, positioning items [ie, Velcro straps], upper extremity props [ie, ball, can, cards], lower extremity props/equipment [ie, blocks, ramps]) | Lower extremity ergometer (6) |
|                                    | Lower extremity ergometer with transcutaneous stimulation (25) |
|                                    | Upper & lower extremity ergometer with transcutaneous stimulation (2) |
| Ergometer (34)                     | Upper extremity ergometer with transcutaneous stimulation (1) |
| (eg, arm crank, hand cycle, tricycle, stationary bike, leg cycle) | Lower extremity ergometer (6) |
| Gait aids (30)                     | Upper extremity ergometer with transcutaneous stimulation (1) |
| (eg, gait aids such as a walker or overhead suspension with body weight support) | Lower extremity ergometer (6) |
| Weight machine or free weights (18) | Upper extremity ergometer with transcutaneous stimulation (2) |
| Standing frame or tilt table (12) | Gait aids (30) |
| Stairs or stair machine (8)       | Weight machine or free weights (18) |
| Upper extremity device (7)        | Standing frame or tilt table (12) |
| Virtual gaming or interactive exercise computer game (8) | Stairs or stair machine (8) |
| Pool (6)                           | Manual upper extremity device (4) |
| Vibrating platform (6)             | Robotic upper extremity device (3) |
| Body-weight supported elliptical (3) | Virtual gaming or interactive exercise computer game (8) |
| Row ergometer (3)                 | Pool (6) |
| Cross trainer (1)                 | Vibrating platform (6) |
| Jump training device (1)          | Body-weight supported elliptical (3) |
|                                    | Row ergometer (1) |
|                                    | Cross trainer (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.
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. 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. 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. 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. 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 pneumorrhachi* or neuromyelopath*).tw,kw. |
| 18     | (abscess adj3 (spinal or epidural or extradural)).tw,kw.                 |
| 19     | (syringomyel* or hydrosyringomyel* or myclosyringos* or myelosphilis or meningomyelit* or myelosyringos* or syringohydromyel*).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*).kw.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                                                               |

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