Review of Therapeutic Interventions for the Upper Limb Classified by Manual Ability in Children with Cerebral Palsy

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Abstract

The aim of this literature review was to assemble an inventory of intervention strategies utilized for children diagnosed with cerebral palsy (CP) based on the Manual Ability Classification System (MACS). The purpose of the inventory is to guide physicians and therapists in intervention selection aimed at improving upper limb function in children with CP. The following databases were searched: CINAHL (Cumulative Index to Nursing and Allied Health Literature), Cochrane Database of Systematic Reviews, ERIC (Educational Research Information Center), Google Scholar, OTSeeker (Occupational Therapy Systematic Evaluation of Evidence), OVID (Ovid Technologies, Inc.), and PubMed. Inclusion criteria were whether the study (1) identified MACS levels of participants, and (2) addressed the effectiveness of intervention on upper limb function. Overall, 74 articles met the inclusion criteria. The summarized data identified 10 categories of intervention. The majority of participants across studies were MACS level II. The most frequently cited interventions were constraint-induced movement therapy (CIMT), bimanual training, and virtual reality and computer-based training. Multiple interventions demonstrated effectiveness for upper limb improvement at each MACS level. However, there is a need for additional research for interventions appropriate for MACS levels IV and V. To fully develop an intervention inventory based on manual ability, future studies need to report MACS levels of participants, particularly for splinting and therapy interventions used in combination with surgery.

Keywords

- cerebral palsy
- Manual Ability Classification System
- therapy intervention
- surgical intervention
- upper limb

Cerebral palsy (CP) describes “a group of permanent disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal and infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, perception, cognition, communication and behavior, by epilepsy, and by secondary musculoskeletal problems.”¹ Cerebral palsy has been historically categorized topographically and physiologically. Topographically, CP is classified by limb involvement ranging from one limb (monoplegia) to all four limbs (quadriplegia). Physiologically, patients present with tone that can be categorized as spastic, flaccid, rigid, dystonic, or athetoid.

With the development of the Gross Motor Classification System (GMFCS) and the Manual Ability Classification System (MACS), CP is also classified by functional performance. The MACS classifies how children with CP use his or her hands when handling objects in daily activities (► **Table 1**).² The classification reflects the child's typical manual performance, not the child's maximal capacity. The MACS reports on the collaboration of both hands together. The expectation is that most children will remain at the same MACS level over time despite intervention or growth/maturity.³ However, children with CP can make improvements in upper limb function and increase independence with activities of daily living within their MACS level.

Table 1 Manual Ability Classification System

Manual Ability Classification System	
Level I	Handles objects easily and successfully
Level II	Handles most objects, but with somewhat reduced quality and/or speed of achievement
Level III	Handles objects with difficulty; needs help to prepare or modify activities
Level IV	Handles a limited selection of easily managed objects in adapted situations
Level V	Does not handle objects and has severely limited ability to perform even simple actions

(From Eliasson AC, Krumlinde-Sundholm L, Rösblad B, et al. The Manual Ability Classification System (MACS) for children with cerebral palsy: scale development and evidence of validity and reliability. *Dev Med Child Neurol* 2006;48(7):549–554.)

Therapists and physicians typically use CP classifications, tone assessments, and functional outcome measures to guide their interventions. The purpose of this literature review is to identify and categorize therapeutic interventions used to treat the spastic upper limb in children with CP based on MACS levels. The aim is to create an inventory of interventions that will guide therapists and physicians in selecting appropriate upper limb interventions based on MACS levels when working with children with CP.

Method

A review of the literature was conducted in May and June of 2015 to identify therapeutic interventions for the upper limb in children with CP for each level of MACS. Relevant articles were identified using the key words “manual ability classification system” to search CINAHL (Cumulative Index to Nursing and Allied Health Literature), Cochrane Database of Systematic Reviews, ERIC (Educational Research Information Center), Google Scholar, OTSeeker (Occupational Therapy Systematic Evaluation of Evidence), OVID (Ovid Technologies, Inc.), and PubMed from January 2006 to June 2015. The start date of 2006 was selected because the first article on MACS was published in 2006.²

Titles and abstracts identified in the search were reviewed by three reviewers to determine if the articles met inclusion criteria for a full review. Articles were included in the review if (1) they contained MACS levels of the participants with CP, and (2) if they were research studies assessing the effectiveness of therapeutic intervention and its impact on upper limb function in children with CP. Upper limb function was defined as changes in range of motion (ROM), strength, dexterity, sensation, pain, unilateral or bimanual hand function, and independence with daily activities that were objectively measured by standardized assessments. Articles were excluded if they did not meet the inclusion criteria, if the publication was not available in English, or if the primary tone of the participants was dystonia or choreoathetosis. The three re-

viewers reconciled any differences on inclusion and exclusion of reviewed articles by a majority opinion.

Levels of evidence included in the review ranged from randomized controlled trials to case studies, according to the Oxford center of evidence-based medicine. Mechanism-based reasoning, expert opinions, and commentaries were not included. When systematic reviews of intervention were identified, the articles included in the review were individually analyzed to determine eligibility for the study. Data extracted from the selected articles included citation, type of intervention, type of study, assessments used, outcome of the intervention, MACS levels, age, and subtype of CP of participants. Data from the studies were summarized by type of intervention and MACS levels.

Results

Utilizing the keywords, manual ability classification system, 1,524 citations were identified: CINAHL = 76, Cochrane Database of Systematic Reviews = 0, ERIC = 17, Google Scholar = 953, MEDLINE = 104, OTSeeker = 7, and PubMed = 367. After the titles and abstracts were reviewed, 1,291 were excluded; after a review of the full-text articles, 74 articles met the inclusion criteria for the review (► **Table 2**). The summarized data from the review identified 10 categories of intervention. The intervention categories are listed based on the number of articles identified from most frequent to least frequent: (1) constraint-induced movement therapy (CIMT), (2) bimanual training, (3) virtual reality-, web-, and computer-based interventions, (4) therapy intervention in conjunction with botulinum toxin A (BoNT), (5) goal-directed/task-oriented therapy, (6) splints and Kinesio Tape, (7) home programs, (8) therapy intervention in conjunction with surgical intervention, (9) exercise and strengthening, and (10) other interventions including handwriting, mirror therapy, somatosensory training, motivation, electrical stimulation, and metronome training. Interventions were included in the “other” category if they were discussed in less than four articles included in the review.

Constraint-Induced Movement Therapy

Constraint-induced movement therapy (CIMT) is a treatment model that uses a restraint on the dominant upper limb to enable intensive use of the involved upper limb during structured tasks that are planned and shaped by a therapist. Protocols for CIMT have been reported for MACS levels I to IV in the literature and vary in type of restraint utilized, delivery of intervention, and duration of therapy. Reported protocols ranged from the child wearing the restraint outside of therapy for forced use of the involved upper limb to wearing a constraint during individual or group therapy or a combination thereof. Protocols have been modified to include bimanual training and home programs. The number of days per week and hours of intervention range from 2 to 7 days per week for 2 to 10 hours per day over 2 to 8 weeks. The most common model reported is a day-camp model for 6 hours per day for 2 to 3 weeks. Overall, CIMT is consistently reported as

Table 2 Intervention inventory

Intervention category		Citations	MACS levels	Outcome measures
1	Constraint-induced movement therapy: Constraining the dominant hand to enable intensive training of the hemiplegic upper limb	Aarts et al ^{40,41} Cao et al ⁴² Cohen-Holzer et al ^{43,44} de Brito Brandao et al ^{45,46} Deppe et al ⁴⁷ Eliasson et al ⁴⁸ Geerdink et al ⁴⁹ Gelkop et al ⁵⁰ Islam et al ⁵¹ Juenger et al ⁵² Klingels et al ⁵³ McConnell et al ⁵⁴ Motta et al ⁵⁵ Reidy et al ⁵⁶ Sakzewski et al ⁵⁷⁻⁶⁰ Stearns et al ⁶¹ Sutcliffe et al ^{62,63} Thompson et al ⁶⁴ Wallen et al ^{65,66} 27 articles	I-IV	ABILHAND-Kids, AHA, AROM, Box and Blocks, CHEQ, COPM, CPQOL, EMG, fMRI, fNIRS, GAS, Gaitrite System, grip and pinch strength, JTHFT, KIDSCREEN, LIFE-H, MAS, MEG, MMT, MUUL, 9-hole peg test, PEDI, pediatric motor activity log, PROM, QUEST, SHUEE, 6-minute walk test, stereognosis, Timed Up and Go, trained tasks, TS, 2-point discrimination, VOAA-DDD, Wolf Motor Function Test
2	Bimanual training: Repetitive task training using two hands together	Aarts et al ^{40,41} Cohen-Holzer et al ^{43,44} de Brito Brandao et al ⁴⁶ Deppe et al ⁴⁷ Gelkop et al ⁵⁰ Green et al ⁶⁷ Gygax et al ⁶⁸ Hung et al ⁶⁹ Peper et al ⁹ Sakzewski et al ⁵⁷⁻⁶⁰ Speth et al ⁷⁰ 16 articles	I-IV	ABILHAND-Kids, AHA, AROM, Box and Blocks, CHEQ, COPM, CPQOL, GAS, Gaitrite system, grip and pinch strength, JTHFT, KIDSCREEN, motion analysis, MUUL, PEDI, PROM, QUEST, SHUEE, 6-minute walk test, stereognosis, Timed Up and Go, 2-point discrimination, VOAA-DDD
3	Virtual reality-, web-, and computer-based interventions: Technology-based intervention that involves a task-oriented game	Bilde et al ⁶ Diment et al ⁷ Green et al ⁷¹ James et al ⁷² Jannink et al ⁷³ Lorentzen et al ¹⁰ Peper et al ⁹ Rincon et al ⁷⁴ Wu et al ^{75,76} Yoo et al ⁸ 11 articles	I-IV	ABILHAND-Kids, AHA, AMPS, Box and Blocks, CHEQ, COPM, EMG, isodynamometer, JTHFT, KVAP, motion analysis, MUUL, qualitative data, RE-ACTION system, sit to stand, 6-minute walk test, step up, test of playfulness, TVPS
4	Therapy intervention in conjunction with botulinum toxin A: Therapy to improve use of upper limb after reduction of spasticity—splinting, exercise, goal directed, standard of care	Copeland et al ⁷⁷ Eliasson et al ⁴⁸ Elvrum et al ⁷⁸ Fattal-Valevski et al ⁷⁹ Lee et al ⁸⁰ Speth et al ⁷⁰ 6 articles	I-V	AHA, AROM, CCHQ, COPM, CPCHILD, CPQOL, grip strength, JTHFT, MAS, MUUL, PPP, PROM, QUEST, SFQ-C, trained tasks, TS, TVMS-R
5	Goal-directed and task-oriented therapy: Practice of tasks that are meaningful to the patient/family, goal directed	Lowing et al ^{12,14} Palisano et al ⁸¹ Robert et al ¹⁵ Sorsdahl et al ¹⁶ Turker et al ¹⁷ 6 articles	I-V	AROM, CHQ-PF 50, COPM, GAS, GMFM, GMPM, light touch, MAS, motion analysis, MUUL, PEDI, PROM, proprioception, QUEST, Semmes Weinstein, SMC, stereognosis, WeeFIM
6	Splints and Kinesio Tape: Braces, orthoses, or tape used on the upper limb to prevent or correct	Barroso et al ⁸² Kaya Kara et al ²² Louwers et al ²⁰	I-V	ABILHAND-Kids, AHA, BOT-2, GAS, GMFM, House scale, JTHFT, pinch/grip strength,

Table 2 (Continued)

Intervention category	Citations	MACS levels	Outcome measures
deformities, improve functional use, and improve position for hygiene and/or appearance	Ten Berge et al ¹⁹ Yildizgoren et al ⁸³ 5 articles		ROM, WeeFim, Zancolli classification
7 Home programs: Practice of goal-based tasks by the child, led by parent and supported by a therapist in the home ⁴	Bilde et al ⁶ Ferre et al ⁸⁴ Lorentzen et al ¹⁰ Novak et al ¹³ Wu et al ⁷⁵ 5 articles	I–V	AHA, AMPS, CAPE, COPM, EMG, GAS, half-knee standing, isodynamometer, motion analysis, Parenting Stress Index, QUEST, sit to stand, step up, treadmill test, TVPS, 6-minute walk test
8 Therapy intervention in conjunction with surgical intervention: Postoperative therapy—skin care, scar care, splinting, advancing movement, and regaining/improving function	de Bruin et al ⁸⁵ Franca Bisneto et al ⁸⁶ Gong et al ⁸⁷ Ponten et al ²⁸ 4 articles	I–V	AHA, appearance, AROM, COPM, dressing ability, FHT, GAS, House scale, hygiene, ROM, wrist torque (custom made device), Zancolli classification
9 Exercise and strengthening: a progressive use of resistance across a wide variety of activities with the goal to build muscle strength and endurance	Declerck et al ⁸⁸ Elvrum et al ⁷⁸ Johnson et al ⁸⁹ Lee et al ³¹ 4 articles	I–V	AHA, AROM, Assessment of Life Habits Short Form, broad jump, CPQOL, GMFM-88, Jamar dynamometer, JTHFT, motion analysis, MUUL, QUEST, throw a ball, ultrasound, vertical jump, WeeFIM, WOTA-2, 10-MWT, 10 × 5 m sprint
10 Other interventions: Handwriting, mirror therapy, somatosensory training, motivation, e-stim and metronome training	Cheng et al ⁹⁰ Johansson et al ³⁹ Miller et al ³⁸ Riquelme et al ³⁷ Ryan et al ³⁵ Smorenburg et al ³⁶ Yildizgoren et al ⁸³ 7 articles	I–V	AHA, AutoCAD, COPM, Dimensions of Mastery Questionnaire, Frey monofilaments, MAS, Minnesota Handwriting Assessment, PEDI, proprioception, Purdue pegboard, SHUEE, stereognosis, surface EMG, texture recognition, 2-point discrimination, videotaped motion analysis

Abbreviations: AHA, Assisting Hand Assessment; AMPS, Assessment of Motor and Process Skills; AROM, active range of motion; AutoCAD, automated computer aided design; CHEQ, Children's Hand-Use Experience Questionnaire; COPM, Canadian Occupational Performance Measure; CPQOL, Cerebral Palsy Quality of Life Questionnaire; EMG, electromyography; FHT, functional hand test; fMRI, functional magnetic resonance imaging; fNIRS, functional near-infrared spectroscopy; GAS, goal attainment scaling; GMFM-88, Gross Motor Function Measure; JTHFT, Jebsen-Taylor Hand Function Test; KVAP, kinetic visual art program; LIFE-H, Assessment of Life Habits Scale; MACS, Manual Ability Classification System; MAS, Modified Ashworth Scale; MEG, magnetoencephalography; MMT, manual muscle testing; MUUL, Melbourne Assessment of Unilateral Upper Limb Function; PEDI, Pediatric Evaluation of Disability Inventory; PROM, passive range of motion; QUEST, Quality of Upper Extremity Skills Test; ROM, range of motion; SHUEE, Shriners Hospital for Children Upper Extremity Evaluation; TS, Tardieu Scale; TVPS, Test of Visual-Perceptual Skills (nonmotor); VOAA-DDD, Video Observations Aarts and Aarts module Determine Developmental Disregard; Wee-FIM, Functional Independence Measure for Children; WOTA-2, Water Orientation Test Alyn-2; 10-MWT, 10-meter walk test.

an effective treatment in improving upper limb function in children with hemiplegia.⁴

Bimanual Training

Bimanual training is repetitive task practice using two hands to complete a task. This intervention approach has been described for MACS levels I to IV and ranges from being incorporated into traditional standard of care occupational therapy to high-intensity training. Hand–arm bimanual intensive training (HABIT) was developed to address bimanual coordination during daily activities using similar principles of CIMIT including intensive structured practice.⁵ Bimanual

therapy and CIMIT are used simultaneously and may be combined with home programs and goal-directed therapy. Bimanual therapy is frequently used after CIMIT to incorporate unilateral upper limb gains into functional two-handed skills. Bimanual therapy has been reported as equally effective in improving hand function as CIMIT.⁴

Virtual Reality-, Web-, and Computer-Based Interventions

Virtual reality- and computer-based therapy are technology-based interventions that use a computer-simulated, task-oriented game to motivate the child to engage in repetitive task

practice.⁶ This approach combines engagement and motivation to succeed at the game while working on specific active range of motion (AROM) with the overall aim of improving function.^{7,8} This technology has been reported in the literature for MACS levels I to IV as a means of engaging children with CP in activities targeting bimanual control,⁹ functional strength, and motor ability.^{6,10} The literature has shown that participants in virtual reality-, web-, and computer-based interventions have the potential for improving muscle activation and functional muscle strength as well as increasing overall physical engagement.⁶⁻⁸ However, overall evidence is insufficient; more robust randomized controlled trials are needed to determine the effectiveness of these interventions.

Therapy Intervention in Conjunction with Botulinum Toxin A

Botulinum toxin A (BoNT-A) is a neuromuscular paralyzing agent that produces dose-dependent chemical denervation when injected into muscles resulting in reduced muscle activity.¹¹ The aim of the treatment is to produce a selective reduction in muscle spasticity to improve active and passive functions of the upper limb, depending on the goals and needs of the patient and family. Active functions include the ability to use the limb during functional tasks, with improved grasp and release, reaching, and motion, as well as an improved ability to use the upper limb during daily activities. Passive functions include improved hygiene, reduction in pain, and improved ease of care by a caregiver. Botulinum toxin A is considered an appropriate treatment option for patients with CP with all levels of manual ability due to the range of active and passive functions that have the potential to be addressed. Botulinum toxin A should not be used in isolation, but should be accompanied by planned occupational therapy.¹¹

Goal-Directed and Task-Oriented Therapy

Goal-directed and task-oriented therapy focuses on everyday skills in the child's natural environment with the goal of improving performance and increasing independence with daily activities. The therapist, child, and family collaborate to set goals with the therapist providing strategies for task-specific practice to utilize a motor learning approach.^{12,13} Based on the literature review, this intervention strategy has been used for all MACS levels and is effective for improvement of basic motor abilities, increased independence with self-care, and goal attainment.¹⁴⁻¹⁷ Overall, goal-directed therapy is effective in improving hand function and self-care skills.⁴ It is frequently combined with other intervention strategies including CIMT, bimanual training, and home programs.

Splints and Kinesio Tape

Splints are removable external devices used to support a weak or ineffective joint or muscle, prevent or correct joint deformities, improve functional use of the upper limb, and improve position for hygiene and/or outward appearance.¹⁸ Although there is little published evidence to support the use of hand splints in children with neurologic conditions, splints continue to be widely prescribed for all MACS levels in an effort to improve upper limb skills and functional activities.

There is evidence to support the use of thumb opponens splints to improve hand function in children with unilateral CP,¹⁹ and bracing of the wrist and thumb to improve spontaneous use of the affected upper limb in bimanual activities.²⁰

Kinesio taping is a technique that uses a thin, elastic, adhesive, latex-free material that can be stretched in the longitudinal plane. It is used at all MACS levels to reduce pain, facilitate or inhibit muscle activity, prevent injuries, reposition joints, aid the lymphatic system, support postural alignment, and improve proprioception. Kinesio Tape techniques are used on children with CP to increase upper limb function by improving ROM, selective finger movements, and fine motor manipulation for goal-directed movement. Select studies show an increase in stability of the shoulder and hand, as well as supporting alignment during reaching and grasping.^{21,22} Kinesio Tape is considered a promising addition to treatment; however, additional research is needed to prove its efficacy.

Home Programs

Occupational therapists routinely use home programs for all MACS levels as an adjunct to concurrent ongoing outpatient therapy, as well as, when outpatient therapy is not available, feasible or affordable. Home programs are individualized multimodal interventions that target body structure, activities, and participation problems identified collaboratively by the parents and the therapist. Novak et al conducted a randomized study showing home programs were clinically effective as demonstrated by improvements in upper limb function and goal attainment if implemented 17.5 times per month for an average of 16.5 minutes per session.¹³ This equates to roughly an hour a week of home program intervention.

Therapy Intervention in Conjunction with Surgical Intervention

Upper extremity surgery in children with CP is a common intervention utilized for all MACS levels to change or alter anatomy, as a means to increase function, improve ability to complete hygiene, improve aesthetics, or prevent further deformity. Various upper limb surgical procedures for the hand, wrist, forearm, and elbow are often used concomitantly. Specific surgical technique articles and their results have been published regarding treatment of elbow flexion contractures,^{23,24} swan neck deformities,²⁵ and thumb in palm deformity.²⁶ Additional literature reflects the vast number of surgeries performed on the wrist and forearm to correct deformity, and place the wrist and forearm in a more functional position.^{27,28} Outcomes after surgery report greater patient satisfaction when they address not only functional limitations but also aesthetics.^{26,27}

Therapy after surgery is an important component impacting outcomes. Referring surgical patients for postoperative hand therapy is essential for optimum patient care and recovery. Scar management, proper splinting, ROM, muscle re-education for transfers, and functional training on daily activities to help ensure good surgical outcomes.²⁶⁻²⁸ The timing of surgery is also critical. The patient must be cooperative with an examination to

determine the amount of functional use as well as compliant with postoperative protocols.²⁷

Unfortunately, the literature is limited regarding the relationship between MACS level and surgery. The articles that reported MACS level with surgery found that patients with high MACS levels have greater improvements in function and overall satisfaction. Tendon transfers and tendon releases for patients with higher MACS levels have improved use of the hand in bimanual activities.²⁸ Even children with a poor functioning passive helper hand showed improvement in efficacy of hand use.²⁸ Patients with low MACS levels had greater improvements in hygiene following surgery.²⁹ Future research on the effectiveness of surgical and postoperative therapy interventions that reports MACS levels is needed to delineate surgical interventions by manual ability.

Exercise and Strengthening

Strength training and exercise involves applying a progressive use of resistance across a variety of specific activities to build muscle strength and endurance.^{4,30} Strength training methods and protocols in the pediatric population with a diagnosis of CP vary widely and may include isokinetic exercises, concentric or eccentric exercises, or engagement in sport or leisure activities.³⁰ Although exercises can be implemented as an isolated intervention, typically a combination of exercise with other intervention strategies is utilized.³⁰ One novel study specifically explored the comprehensive hand repetitive intensive strengthening training (CHRIST) method applied to the use of a low-speed upper limb treadmill program.³¹ The evidence on the effectiveness of strength training to improve upper limb function is inconclusive due to the variability of types, duration, and intensity of strength training programs evaluated,³⁰ suggesting the need for additional randomized controlled trials with specific guidelines to better understand the impact of exercise on the upper limb.

Other Therapeutic Interventions

The final intervention category consists of other therapeutic interventions found in less than four articles included in the literature review. These interventions include handwriting, mirror therapy, somatosensory training, mastery motivation, electrical stimulation, and metronome training.

Handwriting

Children with CP have a higher prevalence of handwriting problems than those in the general population.^{32,33} Early identification and implementation of remedial strategies are important for these students as delays may lead to other academic and interpersonal problems at school.³⁴ Handwriting can be addressed using remedial or compensatory strategies such as modification of the pencil, the technique in holding the pencil, practice of writing including letter formation and orientation of written work, technology, or the sitting arrangement of the patient during handwriting.³⁵

Mirror Therapy

Mirror therapy is a noninvasive treatment strategy that involves placing a mirror along the midsagittal plane in

between both upper limbs. When the patient looks into the mirror, an illusion is created that both arms are moving in perfect symmetry. This intervention has been linked to increased motor function in children with CP.³⁶

Somatosensory Training

Somatosensory and sensorimotor interventions include repetitive touch stimulation, two-point discrimination training, pain pressure thresholds, stereognosis, and proprioception training, which are being utilized to improve somatosensory processing.³⁷

Mastery Motivation

Mastery motivation is a personal characteristic leading an individual to persist in accomplishing challenging problems and complete complex tasks and is unrelated to any other health states or diagnoses.³⁸ Mastery motivation may serve as a predictor of occupational performance following upper limb intervention in children with a diagnosis of CP.³⁸

Electrical Stimulation

Neuromuscular electrical stimulation (NMES) is used to elicit muscle contraction using electric impulses to improve active motion and strength to reduce spasticity and improve function.

Metronome Training

The interactive metronome is a trademarked training method that is used as a method to improve motor control and rhythmicity in adults and children with various diagnoses.³⁹

Further Considerations

After sorting the articles into intervention categories, the articles were broken down further to identify the number of participants within each level of MACS for each intervention category. Articles included identified MACS classification for each participant, the number of participants selected to receive different types of treatment in controlled studies, and if the study demonstrated at least one clinically or statistically significant improvement in upper limb function as measured by a standardized assessment (→ Table 2). Out of the 74 articles included in the review, 69 articles met the

Fig. 1 Manual Ability Classification System (MACS) Level I participants.

Fig. 2 Manual Ability Classification System (MACS) level II participants.

Fig. 3 Manual Ability Classification System (MACS) level III participants.

Fig. 4 Manual Ability Classification System (MACS) level IV participants.

above criteria. The number of participants described in the 69 articles was calculated for each intervention category according to MACS levels (►Figs. 1–5). MACS level II had a significantly higher number of participants ($n = 664$) compared with the other four levels. MACS levels I ($n = 318$) and III ($n = 223$) had a moderate number of participants and MACS levels IV ($n = 75$) and V ($n = 41$) had a low number of participants. The breakdown by MACS levels begins to delineate the intervention inventory and shows the most common intervention strategies reported according to manual ability.

Fig. 5 Manual Ability Classification System (MACS) level V participants.

Conclusion

The MACS is a valid and reliable classification system with proven clinical utility.^{2,3} A review of the literature demonstrates that multiple interventions are effective to treat the upper limb in children with CP at each level of MACS. Children classified as MACS level 1 have good manual ability and overall are independent with daily tasks. They may participate in therapy to maximize unilateral or bimanual function or to achieve a high-level goal, but typically do not need more invasive interventions such as BoNT-A and surgery, which is reflected in ►Fig. 1. Children classified as MACS level II are typically independent with daily activities but often use alternative strategies to complete tasks and display varying degrees of nonuse of the involved upper limb. ►Fig. 2 shows that CIMT followed by bimanual training are the most commonly reported therapeutic interventions to improve upper limb function for children classified as MACS level II. Children classified as MACS level III require set-up or modifications of daily tasks to be successful. ►Fig. 3 displays multiple interventions with comparable numbers of participants. There is a slight increase for CIMT, bimanual, and goal-directed therapy, demonstrating that a variety of interventions are appropriate, and that one type of intervention has not emerged as the most common. The most frequent intervention reported for children classified as MACS level IV was goal-directed therapy with a decrease in CIMT and bimanual training (►Fig. 4). This is important to note because MACS level IV children typically do not have the manual ability or endurance to successfully engage in intensive unilateral or bimanual task performance. Children classified as MACS level V have severely limited ability to perform simple manual tasks. The most frequently reported intervention is the use of BoNT-A injections combined with therapy to improve hygiene, reduce pain, or to improve ease of care by the caregiver (►Fig. 5).

We created this inventory of interventions to categorize various treatment strategies by MACS levels as a guide to physicians and therapists when selecting appropriate treatment according to the child's manual ability. A limitation of this review is that the MACS is only valid for children ≥ 4

years old; therefore, it does not capture intervention strategies for children under the age of 4. Most of the participants in this review were MACS level II with hemiplegia, indicating more research is needed on specific interventions for other MACS levels, especially levels IV and V. Constraint-induced movement therapy, bimanual training, and virtual reality/computer-based interventions were more rigorously evaluated compared with the other interventions. Additional research on interventions related to MACS levels is recommended for areas such as surgery and splinting to develop a more comprehensive intervention inventory tool. Guidelines for treatment based on MACS levels should be used in conjunction with an individual evaluation and a treatment plan designed to meet the specific needs of the child.

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