



MOTOR AND SENSORY IMPAIRMENT REHABILITATION POST ACQUIRED BRAIN INJURY

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Conflict of Interest

In the context of ERABI development, the term “conflict of interest” (COI) refers to situations in which an author or ERABI staff member’s financial, professional, intellectual, personal, organizational or other relationships may compromise their ability to independently conduct this evidence-based review. No limiting conflicts were identified.

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Greetings from Dr. Robert Teasell,

Professor and Chair-Chief of Physical Medicine and Rehabilitation



The Collaboration of Rehabilitation Research Evidence (CORRE) team is delighted to present the Evidence-Based Review of moderate to severe Acquired Brain Injury (ERABI) *Motor and Sensory Impairment Rehabilitation Post Acquired Brain Injury*. Through collaboration of researchers, clinicians, administrators, and funding agencies, ERABI provides an up-to-date review of the current evidence in brain injury rehabilitation. ERABI synthesizes the research literature into a utilizable format, laying the foundation for effective knowledge transfer to improve healthcare programs and services.

We offer our heartfelt thanks to the many stakeholders who are able to make our vision a reality. Firstly, we would like to thank the Ontario Neurotrauma Foundation, which recognizes ERABI's capacity to lead in the field of brain injury evidence-based reviews and is committed to funding it. We would also like to thank the co-chairs of ERABI, Dr. Mark Bayley (University of Toronto) and Dr. Shawn Marshall (University of Ottawa) for their invaluable expertise and stewardship of this review. Special thanks to the authors for generously providing their time, knowledge and perspectives to deliver a rigorous and robust review that will guide research, education and practice for a variety of healthcare professionals. We couldn't have done it without you! Together, we are building a culture of evidence-based practice that benefits everyone.

We invite you to share this evidence-based review with your colleagues, patient advisors that are partnering within organizations, and with the government agencies with which you work. We have much to learn from one another. Together, we must ensure that patients with brain injuries receive the best possible care every time they require rehabilitative care – making them the real winners of this great effort!

Robert Teasell, MD FRCPC

TABLE OF CONTENTS

Preface 7

- About the Authors7
- Purpose8
- Key Concepts8
- Methods10
- Interpretation of the Evidence.....11
- Strength of the Evidence11

Summary of the Evidence14

Introduction23

Motor Impairment24

- Upper Extremity Interventions24**
 - Constraint Induced Movement Therapy 24
 - Hand Splinting and Stretching 26
 - Interventions for Fine Motor Coordination 27
 - Virtual Reality for Upper Extremity Rehabilitation 31
- Lower Extremity Interventions.....32**
 - Partial Body Weight Supported Gait Training 32
 - Multimodal Interventions 34
 - Virtual Reality for Lower Extremity Rehabilitation 38
- Combined Upper and Lower Extremity Interventions.....39**
 - Virtual Reality 39
- Exercise Programs.....41**

Aerobic Training	41
Physiotherapy	50
Spasticity Interventions	52
Botulinum Toxin Injections	52
Nerve Blocking Agents	56
Electrical Stimulation.....	58
Oral Antispasticity Drugs.....	59
Intrathecal Baclofen	61
Casting.....	67
Adjustable Orthosis	70
Hand Splinting and Stretching	70
Multimodal Interventions	72
Visual Dysfunction	75
Vestibular Dysfunction	79
Olfactory Dysfunction	83
Pain Post TBI	84
Assessing Pain Post TBI	88
Visual Analog Scale	88
Numeric Rating Scale	88
McGill Pain Questionnaire	88
Headache Disability Inventory	88
Headache Diary	89
Pain Syndromes Post ABI	89
Neuropathic Pain.....	89
Central Pain Syndromes.....	89

Post Traumatic Headaches 90

Non-Pharmacological Interventions for Pain and Post Traumatic Headache90

Biofeedback to Manage Post Traumatic Headache 91

Cognitive Behavioural Therapy 92

Relaxation Training 93

Manual Therapy 93

Acupuncture 94

Cryotherapy and Thermotherapy 94

Yoga and Mindfulness 95

Pharmacological Management of Pain and Post Traumatic Headache96

Anticonvulsants 96

Antidepressants 99

Opioids 99

Cannabinoids 100

Conclusions.....100

References.....102

Preface

About the Authors

ERABI is internationally recognized and led by a team of clinicians and researchers with the goal of improving patient outcomes through research evidence. Each ERABI module is developed through the collaboration of many healthcare professionals and researchers.



Shannon Janzen, MSc, is a research associate and the project coordinator for the Evidence-Based Review of Acquired Brain Injury (ERABI). Her research interests focus on the integration of best evidence into clinical practice to optimize patient outcomes, with an emphasis on knowledge translation initiatives.



Amber Harnett, MSc, BScN (candidate), CNF scholar, completed her MSc in pathology at Western University and is currently a first-year nursing student in the accelerated BScN program at Western University. Passionate about supporting and advocating for those with brain injuries, she also works as a research coordinator to improve the rehabilitation system through research synthesis, guideline development, knowledge translation, education and outreach in the CORRE lab at Parkwood Institute.



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Purpose

The Evidence-Based Review of Acquired Brain Injury (ERABI) is a systematic review of the rehabilitation literature of moderate to severe acquired brain injuries (ABI). It is an annually updated, freely accessible online resource that provides level of evidence statements regarding the strength of various rehabilitation interventions based on research studies. The ERABI is a collaboration of researchers in London, Toronto and Ottawa. Our mission is to improve outcomes and efficiencies of the rehabilitation system through research synthesis, as well as from providing the foundational research evidence for guideline development, knowledge translation, and education initiatives to maximize the real-world applications of rehabilitation research evidence.

Key Concepts

Acquired Brain Injury

For the purposes of this evidence-based review, we used the definition of ABI employed by the [Toronto Acquired Brain Injury Network](#) (2005). ABI is defined as damage to the brain that occurs after birth and is not related to congenital disorders, developmental disabilities, or processes that progressively damage the brain. ABI is an umbrella term that encompasses traumatic and non-traumatic etiologies.

Table 1 | Defining Acquired Brain Injury

Included in ABI definition	Excluded from ABI definition
<p>Traumatic Causes</p> <ul style="list-style-type: none"> • Motor vehicle accidents • Falls • Assaults • Gunshot wounds • Sport Injuries <p>Non-traumatic Causes</p> <ul style="list-style-type: none"> • Tumours (benign/meningioma only) • Anoxia • Subarachnoid hemorrhage (non-focal) • Meningitis • Encephalitis/encephalopathy (viral, bacterial, drug, hepatic) • Subdural Hematoma 	<p>Vascular and Pathological Incidents</p> <ul style="list-style-type: none"> • Intracerebral hemorrhage (focal) • Cerebrovascular accident (i.e., stroke) • Vascular accidents • Malignant/metastatic tumours <p>Congenital and Developmental Problems</p> <ul style="list-style-type: none"> • Cerebral Palsy • Autism • Developmental delay • Down’s syndrome • Spina bifida with hydrocephalus <p>Progressive Processes</p> <ul style="list-style-type: none"> • Alzheimer’s disease • Pick’s disease • Dementia • Amytrophic Lateral Sclerosis • Multiple Sclerosis • Parkinson’s disease • Huntington’s disease

Given that ‘ABI’ can have multiple definitions, studies with an ‘ABI’ population can be equally heterogeneous in terms of the sample composition. Such studies may include any combination of persons with TBI, diffuse cerebrovascular events (i.e., subarachnoid hemorrhage) or diffuse infectious disorders (i.e., encephalitis or meningitis). The vast majority of individuals with ABI have a traumatic etiology; therefore, much of the brain injury literature is specific to TBI. The terms ABI and TBI have been used intentionally throughout ERABI to provide more information about populations where relevant.

Moderate to Severe Injury

ABI severity is usually classified according to the level of altered consciousness experienced by the patient following injury (Table 2). The use of level of consciousness as a measurement arose because the primary outcome to understand the severity of an injury is the Glasgow Coma Scale. Consciousness levels following ABI can range from transient disorientation to deep coma. Patients are classified as having a mild, moderate or severe ABI according to their level of consciousness at the time of initial assessment. Various measures of altered consciousness are used in practice to determine injury severity. Common measures include the Glasgow Coma Scale (GCS), the duration of loss of consciousness (LOC), and the duration of post-traumatic amnesia (PTA).

Table 2 | Defining Severity of Traumatic Brain Injury, adapted from Veterans Affairs Taskforce (2008) and Campbell (2000)

Criteria	Mild	Moderate	Severe	Very Severe
Initial GCS	13-15	9-12	3-8	Not defined
Duration LOC	< 15minutes*	<6 hours	6-48 hours	>48 hours
Duration PTA	< 1hour*	1-24 hours	1-7 days	>7 days
	*This is the upper limit for mild traumatic brain injury; the lower limit is any alteration in mental status (dazed, confused, etc.).			

Methods

An extensive literature search using multiple databases (CINAHL, PubMed/MEDLINE, Scopus, EMBASE, and PsycINFO) was conducted for articles published in the English language between 1980–March 2020 that evaluate the effectiveness of any intervention/treatment related to ABI. The references from key review articles, meta-analyses, and systematic reviews were reviewed to ensure no articles had been overlooked. For certain modules that lacked research evidence the gray literature, as well as additional databases, were searched in order to ensure the topic was covered as comprehensively as possible.

Specific subject headings related to ABI were used as the search terms for each database. The search was broadened by using each specific database’s subject headings, this allowed for all other terms in the database’s subject heading hierarchy related to ABI to also be included. The consistent search terms used were “head injur*”, “brain injur*”, and “traumatic brain injur*”. Additional keywords were used specific to each module. A medical staff librarian was consulted to ensure the searches were as comprehensive as possible.

Every effort was made to identify all relevant articles that evaluated rehabilitation interventions/treatments, with no restrictions as to the stage of recovery or the outcome assessed. For each module, the individual database searches were pooled, and all duplicate references were removed. Each article title/abstract was then reviewed; titles that appeared to involve ABI and a treatment/intervention were selected. The remaining articles were reviewed in full.

Studies meeting the following criteria were included: (1) published in the English language, (2) at least 50% of the population included participants with ABI (as defined in Table 1) or the study independently reported on a subset of participants with ABI, (3) at least three participants, (4) ≥50% participants had a moderate to severe brain injury, and (5) involved the evaluation of a treatment/intervention with a measurable outcome. Both prospective and retrospective studies were considered. Articles that did not meet our definition of ABI were excluded.

Interpretation of the Evidence

The levels of evidence (Table 3) used to summarize the findings are based on the levels of evidence developed by Sackett et al. (2000). The levels proposed by Sackett et al. (2000) have been modified; specifically, the original ten categories have been reduced to five levels. Level 1 evidence pertains to high quality RCTs (PEDro ≥ 6) and has been divided into two subcategories, level 1a and level 1b, based on whether there was one, or more than one, RCT supporting the evidence statement.

The evidence statements made in evidence-based reviews are based on the treatment of groups rather than individuals. There are times when the evidence will not apply to a specific case; however, the majority of patients should be managed according to the evidence. Ultimately, the healthcare professional providing care should determine whether an intervention is appropriate, and the intensity in which it should be provided, based on their patient. Furthermore, readers are asked to interpret the findings of studies with caution as evidence can be misinterpreted. The most common scenario occurs when results of a trial are generalized to a wider group than the evidence allows. Evidence is a tool, and as such, the interpretation and implementation of it must always be done with the limitations in mind.

Table 3 | Levels of Evidence

Level	Research Design	Description
1A	Randomized Controlled Trial (RCT)	More than one RCT with PEDro score ≥ 6 . Includes within subject comparisons, with randomized conditions and crossover designs
1B	RCT	One RCT with PEDro ≥ 6
2	RCT	One RCT with PEDro < 6
	PCT	Prospective controlled trial (not randomized)
	Cohort	Prospective longitudinal study using at least two similar groups with one exposed to a particular condition
3	Case Control	A retrospective study comparing conditions including historical controls
4	Pre-Post test	A prospective trial with a baseline measure, intervention, and a post-test using a single group of subjects
	Post-test	A prospective intervention study using a post intervention measure only (no pre-test or baseline measurement) with one or more groups
	Case Series	A retrospective study usually collecting variables from a chart review
5	Observational study	Using cross sectional analysis to interpret relations
	Clinical Consensus	Expert opinion without explicit critical appraisal, or based on physiology, biomechanics or "first principles"
	Case Reports	Pre-post or case series involving one subject

Strength of the Evidence

The methodological quality of each randomized controlled trial (RCT) was assessed using the Physiotherapy Evidence Database (PEDro) rating scale developed by the Centre for Evidence-Based

Physiotherapy in Australia (Moseley et al., 2002). The PEDro is an 11-item scale; a point is awarded for ten satisfied criterion yielding a score out of ten. The first criterion relates to external validity, with the remaining ten items relating to the internal validity of the clinical trial. The first criterion, eligibility criteria, is not included in the final score. A higher score is representative of a study with higher methodological quality.

MOTOR AND SENSORY IMPAIRMENT REHABILITATION POST ACQUIRED BRAIN INJURY

Summary of the Evidence

Intervention	Key Point Level of Evidence
Upper Extremity Interventions	
Constraint Induced Movement Therapy	<p>Constraint induced movement therapy may improve function and use of the affected upper limb post ABI.</p> <p><i>There is level 4 evidence (from two pre-posts; Shaw et al., 2005; Page & Levine, 2003) that constraint induced movement therapy (CIMT) or modified CIMT may improve upper extremity function in individuals post ABI.</i></p>
Hand Splinting and Stretching	<p>Overnight hand splinting may not improve upper limb function post ABI. Soft hand splinting, but not manual therapy, may be beneficial for improving hand opening post ABI.</p> <p><i>There is level 1b evidence (from one randomized controlled trial; Lannin et al., 2003) that nocturnal hand splinting may not improve upper extremity range of motion or function compared to standard care in individuals post ABI.</i></p> <p><i>There is level 1b evidence (from one randomized controlled trial; Thibaut et al., 2015) that soft hand splinting, but not manual therapy, may improve hand opening in individuals post ABI.</i></p>
Interventions for Fine Motor Coordination	<p>Functional dexterity tasks may be superior to tabletop fine motor control activities for improving fine motor coordination post ABI.</p> <p><i>There is level 2 evidence (from one randomized controlled trial; Neistadt, 1994) that functional retraining activities may be more effective than tabletop fine motor control retraining activities for improving fine motor function in the dominant hand in individuals post ABI.</i></p> <p>Gesture recognition biofeedback and visual feedback-based training may improve fine motor function post ABI.</p> <p><i>There is level 4 evidence (from one pre-post; Kriz et al., 1995) that visual feedback-based grip force training may improve tracking accuracy and transfer tasks in individuals post ABI.</i></p> <p><i>There is level 2 evidence (from one prospective controlled trial; Yungher & Craelius, 2012) that gesture recognition biofeedback may improve fine motor function compared to standard repetitive training without feedback in individuals post ABI.</i></p> <p>Finger sequencing tasks may improve fine motor performance speeds, but not error rates.</p>

	<p><i>There is level 2 evidence (from one prospective controlled trial; Korman et al., 2018) that finger sequencing training may increase performance speed on this task, but not significantly improve error rates in individuals post ABI.</i></p>
Virtual Reality for Upper Extremity Rehabilitation	<p>Electrical muscle stimulation with passive exercise may improve lower extremity muscle atrophy post ABI.</p> <p>Sit-to-stand training and Intensive Mobility Training may improve lower extremity motor function post ABI.</p> <p>Motor rehabilitation may improve high-level mobility and ankle joint mechanisms during running in individuals with severe TBI</p> <p><i>There is level 2 evidence (from one prospective controlled trial; Sietsema et al., 1993) and level 4 evidence (from one pre-post; Mumford et al., 2012) that virtual reality training may improve dexterity as well as reaching accuracy and movements post ABI.</i></p>
Lower Extremity Interventions	
Partial Body Weight Supported Gait Training	<p>Partial body weight supported gait training likely does not improve ambulation, mobility, or balance when compared to conventional gait training post ABI.</p> <p><i>There is level 2 evidence (from one randomized controlled trial; Brown et al., 2005) that body weight supported treadmill training may not improve ambulation or mobility compared to conventional gait training in individuals post ABI.</i></p> <p><i>There is level 1b evidence (from one randomized controlled trial; Wilson et al., 2006) that physical therapy with partial weight-bearing gait training may not improve ambulation, mobility, or balance compared to standard physical therapy in individuals post ABI.</i></p> <p>Robotic assisted treadmill training may be similar to manually assisted treadmill training at improving gait speed and mobility post ABI.</p> <p><i>There is level 2 evidence (from one randomized controlled trial; Esquenazi et al., 2013) that robotic assisted body weight supported treadmill training may not improve ambulation or gait velocity compared to manually assisted treadmill training in individuals post ABI.</i></p>
Multidimensional Interventions	<p>Electrical muscle stimulation with passive exercise may improve lower extremity muscle atrophy post ABI.</p> <p><i>There is level 2 evidence (from one prospective controlled trial; Hirose et al., 2013) that electrical muscle stimulation with passive exercise may reduce lower extremity muscle atrophy compared to passive exercise in individuals post ABI.</i></p> <p>Sit-to-stand training and Intensive Mobility Training may improve lower extremity motor function post ABI.</p>

	<p><i>There is level 1b evidence (from one randomized controlled trial; Canning et al., 2003) that sit-to-stand training combined with usual rehabilitation may improve motor performance in sit-to-stand tasks compared to usual rehabilitation alone in individuals post ABI.</i></p> <p><i>There is level 4 evidence (from one pre-post; Peters et al., 2014) that Intensive Mobility Training may improve ambulation and mobility in individuals post ABI.</i></p> <p>Motor rehabilitation may improve high-level mobility and ankle joint mechanisms during running in individuals with severe TBI.</p> <p><i>There is level 2 evidence (from one prospective controlled trial; Williams et al., 2019) that motor rehabilitation may improve high-level mobility and ankle joint mechanisms during running in individuals with severe TBI.</i></p> <p>Body-weight-support treadmill with handrail support may reduce movement instability compared to other methods of training in individuals post ABI.</p> <p><i>There is level 2 evidence (from one randomized controlled trial; Clark et al., 2012) that body-weight-support treadmill with handrail support may reduce movement instability compared to other methods of training in individuals post ABI.</i></p>
<p>Virtual Reality for Lower Extremity Rehabilitation</p>	<p>Virtual reality can be used for the remediation of motor function in the lower extremities post ABI.</p> <p><i>There is level 1b evidence (from one randomized controlled trial; Cuthbert et al., 2014) that virtual reality training compared to balance training may not be more effective for improving lower extremity function post ABI. However, virtual reality training was shown to improve function independently.</i></p> <p><i>There is level 4 evidence (from one post-test; Foo et al., 2013) that visual feedback may reduce weight-bearing asymmetry in the lower extremities post ABI.</i></p>
<p>Combined Upper and Lower Extremity Interventions</p>	
<p>Combined Upper and Lower Extremity Interventions</p>	<p>Virtual reality training likely improves balance in individuals post ABI, however it may not be more effective than conventional physiotherapy programs.</p> <p><i>There is level 2 evidence (from one pre-post; Ustinova et al., 2014) that virtual reality therapy may improve balance, gait, and functional reaching in individuals post ABI.</i></p> <p><i>There is level 2 evidence (from prospective controlled trial; Schafer & Ustinova, 2013) that activities in a physical environment and a virtual environment improve reaching in individuals with TBI.</i></p>
<p>Exercise Programs</p>	
<p>Aerobic Training</p>	<p>Modafinil has not been shown to be effective in treating fatigue post TBI.</p> <p>Aerobic exercise programs, whether home-based or in the community, appear to improve motor function, balance, and cardiovascular parameters post ABI; further research is needed in order to determine which components of exercise are the most effective for motor rehabilitation post ABI.</p>

	<p><i>There is level 1b evidence (from two randomized controlled trials; Hassett et al., 2009; Hassett et al., 2011) that participating in an exercise program at a fitness-center compared to home-based exercise program may lead to greater program adherence but not significantly different motor results in individuals post ABI and those with greater adherence may be more severely injured.</i></p> <p><i>There is level 1b evidence (Hassett et al., 2012) that circuit training with encouragement and heart rate monitor feedback may not significantly improve performance in individuals post ABI.</i></p> <p><i>There is level 2 evidence (from one randomized controlled trial; Hoffman et al., 2010) that community-based exercise may decrease pain and depression in individuals post ABI.</i></p> <p><i>There is level 2 evidence (from one randomized controlled trial; Driver et al., 2006) that aerobic training compared to vocational rehabilitation may be more effective at improving co-ordination, strength, flexibility, and endurance in individuals post ABI.</i></p> <p><i>There is level 1b evidence (from one randomized controlled trial; Bateman et al., 2001) that exercise programs may improve FIM scores, but not balance or mobility compared to relaxation training in individuals post ABI.</i></p> <p><i>There is level 2 evidence (from one prospective controlled trial; Corral et al., 2014) that exercise programs may improve oxygen uptake and CPC levels in individuals post ABI.</i></p> <p><i>There is level 4 evidence (from one pre-post; Charrette et al., 2016) that multimodal exercise programs may improve gait and mobility in individuals post ABI.</i></p> <p><i>There is level 3 evidence (from one case control; Damiano et al., 2016) that a home-based exercise program may improve stability to the level of healthy controls, but may not improve motor control, mobility, or dual-task performance in individuals post ABI.</i></p> <p><i>There is level 2 evidence (from one prospective controlled trial; Dault & Dugas, 2002) that aerobic dance training compared to musculature training may improve sensory interaction and balance post ABI.</i></p> <p><i>There is level 4 evidence (from one pre-post; Ustinova et al., 2015) that a therapeutic exercise program may improve balance and gait, but not FIM scores in individuals post ABI.</i></p> <p><i>There is level 4 evidence (from one case series and one pre-post; Bhambhani et al., 2005; Chin et al., 2015) that aerobic exercise programs may improve cardiovascular parameters following an ABI.</i></p>
<p>Physiotherapy</p>	<p>Physiotherapy and early intensive rehabilitation management likely improves ambulation and motor function following an ABI.</p> <p><i>There is level 4 evidence (from one case series; Thibaut et al., 2018; and one pre-pos study; Mossberg et al., 2002) that physiotherapy may improve motor outcomes such as ambulation, spasticity and gross motor function following an ABI.</i></p> <p><i>There is level 1b evidence (from one randomized controlled trial; Fan et al., 2020) that early intensive rehabilitation management might be more beneficial for neurologic function and activities of daily living in individuals with moderate TBI.</i></p>
<p>Spasticity Interventions</p>	
<p>Botulinum Toxin Injections</p>	<p>Botulinum toxin type A injections are effective in the management of localized spasticity following an ABI.</p>

	<p><i>There is level 4 evidence (from one pre-post test; Intiso et al., 2014) that botulinum toxin type A injections may be effective in the management of localized spasticity following ABI.</i></p> <p><i>There is level 4 evidence (from one pre-post test; Clemenzi et al., 2012; and one case series; Yablon et al., 1996) that botulinum toxin A injections in conjunction with conventional therapies may improve spasticity and passive ROM in patients with TBI.</i></p> <p>Botulinum toxin injections in combination with casting may be as effective as casting alone at reducing leg spasticity in patients post ABI.</p> <p><i>There is level 1b evidence (from one randomized controlled trial; Verplancke et al., 2005) that botulinum toxin injections in combination with casting may be as effective as casting alone at reducing leg spasticity in patients post ABI.</i></p> <p>Botulinum toxin type A injections, whether through a single point or multisite, likely reduce localized spasticity following ABI.</p> <p><i>There is level 1b evidence (from one randomized controlled trial; Mayer et al., 2008) that receiving botulinum toxin type A through a single motor point or multisite distributed injections are similar at reducing spasticity in individuals with an ABI.</i></p>
<p>Neve Blocking Agents</p>	<p>Phenol blocks of the musculocutaneous nerve may help decrease spasticity and improve range of motion temporarily up to five months post injection in individuals with ABI.</p> <p><i>There is level 4 evidence (from two case series; Keenan et al., 1990; Garland et al., 1984) that phenol nerve blocks may reduce contractures and spasticity at the elbow, wrist, and finger flexors for up to five months post injection in individuals post ABI.</i></p>
<p>Electric Stimulation</p>	<p>Electrical stimulation in combination with tilt table standing and splinting may acutely improve spasticity (6 weeks) in patients post ABI.</p> <p><i>There is level 1b evidence (from one randomized controlled trial; Leung et al., 2014) that electrical stimulation in combination with tilt table standing and splinting may decrease spasticity at 6 weeks post intervention compared to tilt table standing alone in patients with an ABI.</i></p> <p>Electrical stimulation may acutely (24 hours) decrease spasticity in patients post ABI.</p> <p><i>There is level 4 evidence (from one pre-post test; Seib et al., 1994) that electrical stimulation may be effective for decreasing lower extremity spasticity for six or more hours, lasting up to 24 hours, in individuals post ABI.</i></p>
<p>Oral Antispasticity Drugs</p>	<p>Oral baclofen may reduce lower extremity, but not upper extremity, spasticity in individuals with an ABI.</p>

	<p><i>There is level 4 evidence (from one case series; Meythaler et al., 2004) that oral baclofen may improve lower extremity spasticity, but not upper extremity spasticity, in individuals post ABI.</i></p>
<p>Intrathecal Baclofen</p>	<p>Bolus injections of intrathecal baclofen likely produce short-term reductions in upper and lower extremity spasticity and improvements in walking performance post ABI.</p> <p><i>There is level 1b evidence (from one randomized controlled trial; Meythaler et al., 1996) that bolus intrathecal baclofen injections may produce short-term (up to six hours) reductions in upper and lower extremity spasticity compared to placebo following ABI.</i></p> <p><i>There is level 4 evidence (from three pre-post tests; Chow et al., 2015; Horn et al., 2005; 2010) that intrathecal baclofen may reduce spasticity and improve walking performance in ambulatory patients with ABI.</i></p> <p>Intrathecal baclofen may reduce upper and lower extremity spasticity long-term post ABI.</p> <p><i>There is level 4 evidence (from five case series; Wang et al., 2016; Becker et al., 1997; Francois, 2001; Francisco et al., 2005; Stokic et al., 2005; six pre-post tests; Dario et al., 2002; Margetis et al., 2014; Meythaler et al., 1997; 1999a; 1999b; Posteraro et al., 2013; and one post-test; Hoarau et al., 2012a) that intrathecal baclofen may result in long-term reductions in spasticity in both the upper and lower extremities following an ABI.</i></p>
<p>Casting</p>	<p>Serial casting likely improves contractures and spasticity in individuals with an ABI compared to stretching, however, contracture improvement may not be maintained long-term.</p> <p><i>There is level 1b evidence (from one randomized controlled trial; Moseley et al., 2008) that serial casting may improve contractures of the elbow initially, but not long-term, when compared to passive stretching in individuals with an ABI.</i></p> <p><i>There is level 1b evidence (from one randomized controlled trial; Moseley et al., 2008) that serial casting may be superior to passive stretching at improving spasticity of the elbow in individuals post ABI.</i></p> <p>Below-knee casting and stretching might increase passive ankle dorsiflexion in patients post ABI.</p> <p><i>There is level 2 evidence (from one randomized controlled trial; Moseley, 1997) that a below-knee casting and stretching protocol may increase passive ankle dorsiflexion in patients post ABI.</i></p> <p>Serial below-knee casting may improve ankle range of motion and muscle extensibility in patients post TBI, however, this intervention may be associated with tissue breakdown.</p> <p><i>There is level 4 evidence (from one pre-post test; Singer et al., 2003) that weekly below-knee casts may improve ankle range of motion, muscle extensibility, and passive torque in patients post ABI.</i></p>

	<p>Serial casting, whether for a short or long duration, might improve range of motion in individuals with an ABI. However, short duration casting may have a lower complication rate than long duration.</p> <p><i>There is level 3 evidence (from one case control study; Pohl et al., 2002) that short duration (one to four days) and longer duration (five to seven days) serial casting may have similar effects on upper or lower extremity range of motion in individuals post ABI.</i></p>
<p>Hand Splinting and Stretching</p>	<p>Hand splinting combined with stretching may be an effective treatment for spasticity and range of motion.</p> <p><i>There is level 1b evidence (from one randomized controlled trial; Thibaut et al., 2015) that nocturnal hand splinting may not improve upper extremity range of motion or function compared to standard care in individuals post ABI.</i></p>
<p>Multidimensional Interventions</p>	<p>Botulinum toxin injections in combination with casting may be as effective as casting alone at reducing leg spasticity in patients post ABI.</p> <p><i>There is level 2 evidence (from one randomized controlled trial; Verplancke et al., 2005) that botulinum toxin combined with casting may not be more effective than botulinum toxin injections alone in improving leg spasticity in individuals with an ABI.</i></p> <p>Electrical stimulation in combination with tilt table standing and splinting may acutely improve spasticity (6 weeks) in patients post ABI.</p> <p><i>There is level 1b evidence (from one randomized controlled trial; Leung et al., 2014) that electrical stimulation in combination with tilt table standing and splinting may decrease spasticity at 6 weeks post intervention compared to tilt table standing alone in patients with an ABI.</i></p> <p>There is level 1b evidence (from one randomized controlled trial; Lorentzen et al., 2012) that neural tension technique may not be more effective than random passive movement in improving lower extremity spasticity and range of motion in individuals with an ABI.</p> <p><i>Neural tension technique may be just as effective as random passive movement for improving lower extremity spasticity post ABI.</i></p> <p>A program for contracture management consisting of serial casting, botulinum toxin, motor training and splinting may improve joint range but not improve spasticity in individuals with moderate to severe TBI.</p> <p><i>There is level 2 evidence (from one prospective controlled trial; Williams et al., 2019) that motor rehabilitation may improve high-level mobility and ankle joint mechanisms during running in individuals with severe TBI.</i></p>

Visual Dysfunction	
Interventions for Visual Dysfunction	<p>Computer based restitution training and rehabilitation programs directed at improving visual function likely improve the vision of those who sustain a TBI.</p> <p><i>There is level 1b evidence (from one randomized controlled trial; Kasten et al., 1998) and level 2 evidence (from one randomized controlled trial; Kasten et al., 2000) that computer-based restitution training may be effective in improving the vision of those who sustain a TBI compared to visual fixation training.</i></p> <p>Base-in prisms and bi-nasal occluders may be effective in treating ambient vision disturbances.</p> <p><i>There is level 4 evidence (from one pre-post test; Padula et al., 1994) that base-in prisms and bi-nasal occluders can be effective in treating ambient vision disturbances resulting from an ABI.</i></p> <p>Saccadic oculomotor rehabilitation may improve eye movements and reading in patients post ABI.</p> <p><i>There is level 2 evidence (from one prospective controlled trial; Ciuffreda et al., 2006) that saccade visual tracking compared to fixation and pursuit tracking may improve single-line and multi-line reading post ABI.</i></p> <p>Home-based visual vergence therapy be effective in treating binocular vision disorders in individuals with ABI.</p> <p><i>There is level 4 evidence (from one pre-post test; Conrad et al., 2017) that home-based visual vergence therapy be effective in treating binocular vision disorders in individuals with ABI.</i></p>
Vestibular Dysfunction	
Interventions for Vestibular Dysfunction	<p>Combined aerobic dance and slide and step programs may improve balance and coordination post TBI.</p> <p><i>There is level 2 evidence (from one prospective controlled trial; Dault & Duga, 2002) that using a combined aerobic dancing and slide, and step training program may reduce balance and coordination deficits post TBI.</i></p> <p>A vestibular rehabilitation program may improve symptoms of vertigo in patients following TBI.</p> <p><i>There is level 4 evidence (from one pre-post test; Gurr & Moffat, 2001) that vestibular rehabilitation programs, such as a behavioural exposure program, may improve symptoms of vertigo in patients after TBI.</i></p> <p>Vestibular rehabilitation programs, alone or in combination with betahistine dihydrochloride, can improve recovery time for balance disorders in individuals with an ABI.</p>

	<p><i>There is level 2 evidence (from one randomized controlled trial; Naguib & Madian, 2014) that vestibular rehabilitation programs, alone or in combination with betahistine dihydrochloride, can improve recovery time for balance disorders in individuals with an ABI compared to betahistine dihydrochloride alone.</i></p> <p>An individualized dual-task home-based rehabilitation programme may improve balance control in individuals with ABI.</p> <p><i>There is level 1b evidence (from one randomized controlled trial; Peirone et al., 2014) that an individualized dual-task home-based rehabilitation programme may improve balance control in individuals with ABI.</i></p> <p>Particle Repositioning Maneuver may be effective in relieving symptoms of benign paroxysmal positional vertigo in individuals with severe TIB.</p> <p><i>There is level 4 evidence (from one post-test; Motin et al., 2005) that the Particle Repositioning Maneuver may lead to improvements in Positional Nystagmus in individuals with severe TBI.</i></p>
<p>Olfactory Dysfunction</p>	
<p>Interventions for Olfactory Dysfunction</p>	<p>Corticosteroids and olfactory training may improve olfactory dysfunction in individuals with moderate to severe TBI.</p> <p><i>There is level 4 evidence (from one pre-post test; Bratt et al., 2020) that corticosteroids and olfactory training may improve olfactory dysfunction in individuals with moderate to severe TBI.</i></p>
<p>Non-Pharmacological Interventions for Pain and Post Traumatic Headache</p>	
<p>Biofeedback to Manage Post Traumatic Headache</p>	<p>Despite the positive results of the study investigating biofeedback and post traumatic headaches, further research needs to be completed using larger groups and only with those who have moderate and severe TBIs.</p> <p><i>There is Level 2 evidence (from one cohort study; Tatrow et al., 2003) that biofeedback is effective in the treatment of post-traumatic headaches; although, the severity of the participants was not clearly stated.</i></p>
<p>Cognitive Behavioural Therapy</p>	<p>Cognitive behavioural therapy may be useful in managing post-traumatic headaches; however, may not be useful for headache-associated pain.</p> <p><i>There is level 4 evidence (from one pre-post test; Gurr & Coetzer, 2005) that cognitive behavioural therapy may improve post traumatic headache intensity and frequency but not pain, in those who have sustained a mild to severe TBI.</i></p>
<p>Cryotherapy and Thermotherapy</p>	<p>Cold therapy is likely not as effective as manual therapy at reducing post traumatic headache pain in patients post TBI.</p> <p><i>There is level 2 evidence (from one randomized controlled trial; Jensen et al., 1990) that cold therapy may not be as effective as manual therapy for reducing post traumatic headache pain in individuals post ABI.</i></p>

Yoga and Mindfulness

Yoga and mindfulness may improve perceived pain and positively impact quality of life overall.

There is level 4 evidence (from one pre-post test; Combs et al., 2018) that the number of mindfulness and yoga sessions attended is positively correlated with a perceived reduction in pain and an increase in overall health.

Introduction

The primary cause of motor impairment and movement dysfunction post Acquired Brain Injury (ABI) is Upper Motor Neuron Syndrome (UMNS), which can result in positive symptoms of enhanced stretch reflexes (spasticity) and released flexor reflexes in the lower limbs, such as the Babinski sign and mass synergy patterns, as well as negative symptoms including loss of dexterity and weakness (Mayer, 1997). These symptoms of UMNS have physiological implications for muscles that may subsequently develop stiffness and contractures, thereby further negatively affecting effective movement (Mayer, 1997).

For UMNS following brain injury, both the extent and timing of the individual's symptoms should be considered when deciding on a course of action. Focal or diffuse spasticity may appear following an ABI and frequently follow common patterns in the upper and lower limbs (Mayer, 1997). Time post injury is another important consideration as spontaneous neurological recovery may continue for 9 to 15 months post injury. However, the potential for functional motor recovery beyond that point is possible through medical interventions, such as the correction of a deformity or the use of pharmacological agents that allow for improved motor control (Mayer et al., 1996). Motor impairment can also result from the independent effects of prolonged immobilization and bed rest during the acute period. Prolonged immobility affects multiple body systems, although it is the direct effect on the musculoskeletal and cardiovascular systems that impact motor function the most (Bushbacher & Porter, 2000).

Following diffuse central nervous system injury there are potential impairments involving the cognitive, behavioural, and physical domains. It is the physical domain that is emphasized early on within the rehabilitation process, as most acute in-patient rehabilitation programs focus on the improvement of activities of daily living (ADLs) a patient can perform— as assessed by outcome measures such as the Functional Independence Measure or the Barthel Index (Linacre et al., 1994; McDowell, 2006). The emphasis on physical impairments during rehabilitation is common because both the patient and family members are more likely to recognize and acknowledge physical impairments, in contrast to cognitive and behavioural impairments.

This module reviews the available evidence pertaining to interventions for motor and sensory rehabilitation following ABI.

Motor Impairment

Motor rehabilitation is a common focus of interventions provided to an individual post ABI. Motor rehabilitation is essential in helping the patient return to performing their ADLs, thus reestablishing independence post ABI. The following sections evaluate interventions available for upper and lower extremity motor impairment, including spasticity.

Upper Extremity Interventions

Upper limb motor impairments are common in individuals with an ABI (Lannin et al., 2003). Interventions for the upper limb can focus broadly on arm mobility or on more specific outcomes such as finger dexterity. Despite the importance of upper extremity rehabilitation post ABI, there are limited studies evaluating available interventions.

Constraint Induced Movement Therapy

Constraint Induced Movement Therapy (CIMT) is an intervention directed at improving the function of the more affected upper extremity following brain injury. The two primary components involve: 1) intensive motor training of the more affected upper extremity and 2) motor restriction of the less affected upper extremity (Dettmers et al., 2005). CIMT originated from research suggesting that the affected limb post brain injury is negatively impacted by “learned non-use” due to increased dependence on the intact limb (Grotta et al., 2004).

Although there is evidence in the stroke population to suggest that CIMT is clinically effective, many patients do not qualify for this type of therapy, which requires voluntary extension of the wrist and fingers, due to limited movement in the affected upper extremity. A further significant limitation of CIMT is the amount of resources required for its implementation (Grotta et al., 2004). Two studies evaluating the effect of CIMT post Traumatic Brain Injury (TBI) have been identified (Table 4).

TABLE 4 | Constraint Induced Movement Therapy for Upper Extremity Rehabilitation Post ABI

Author, Year Country Study Design Sample Size	Methods	Outcome
Shaw et al. (2005) USA Pre-Post N=22	<p>Population: TBI; Mean Age=39.3yr; Gender: Male=14, Female=8; Mean Time Post Injury=8.9yr.</p> <p>Intervention: Participants received constraint induced movement therapy (CIMT; 6hr, 5 d/wk for 2wk) in the laboratory engaging in massed practice shaping or task specific procedures while wearing a protective safety mitt on their less-affected upper limb (UL) for ≥90% of the time. Participants were encouraged to use the</p>	<ol style="list-style-type: none"> Significant improvements in real-world use across all post-intervention testing occasions as measured by the MAL (mean change=1.6, p<0.001). Significant post-treatment improvements in more affected ULFM scores (mean change=4.2, p<0.001), and WMFT scores (mean change=0.4, p<0.01).

	<p>mitt outside the lab as well. Outcome Measure: Fugl Meyer (FM) Motor Performance Assessment, Wolf Motor Function Test (WMFT), and Motor Activity Log (MAL).</p>	<ol style="list-style-type: none"> Based on the FM scores, the largest gains were in the upper arm, compared to the hand or wrist. Based on a median split (57%) of adherence to mitt wearing outside the lab, less-adherent participants had smaller treatment gains than those who were more-adherent. On the MAL, less adherent participants showed a trend towards smaller gains than more adherent participants (p=0.065).
<p>Page & Levine (2003) USA Pre-Post N=3</p>	<p>Population: TBI; Mean Age=21yr; Gender: Male=2, Female=1. Intervention: Physical and occupational therapy sessions (30min each, 3x/wk for 10 wk) were provided. The less affected upper limb was also restrained (5hr/day for 5days/wk) using modified constraint induced therapy (mCIT). Outcome Measure: Action Research Arm Test (ARAT), Motor Activity Log (MAL), and Wolf Motor Function Test (WMFT).</p>	<ol style="list-style-type: none"> Pre-intervention participants exhibited learned non-use (MAL, Amount of Use scores <1.0). After the intervention, MAL scores improved: Amount of use=2.0 and quality of use=2.2. Participants 1, 2 and 3 had functional improvements on the ARAT (14.0, 5.5, and 6.0 respectively) and the WMFT (1.15, 1.7 and 1.35 respectively).

Discussion

The effectiveness of modified CIMT was studied by Page and Levine (2003), with participants showing improvements in both the amount and quality of use of the more affected limb. CIMT was also studied by Shaw et al. (2005) and showed similar results. Significant improvements were seen in both laboratory and real-world spontaneous use of the more affected upper limb following two weeks of CIMT (Shaw et al., 2005). Although all participants benefited from the intervention, the gains made by those placed in the “less adherent” group were strongly correlated with the participant’s degree of adherence (Shaw et al., 2005). This correlation was not evident in the “more adherent” group; with the authors suggesting that adherence beyond a certain level does not contribute to additional benefits (Shaw et al., 2005). The gains were maintained at one month, however use of the affected limb decreased by 21% at two years post-treatment. Given these two studies, CIMT for the upper extremity appears to have a positive impact on upper limb motor recovery post ABI.

Conclusions

There is level 4 evidence (from two pre-posts; Shaw et al., 2005; Page & Levine, 2003) that constraint induced movement therapy (CIMT) or modified CIMT may improve upper extremity function in individuals post ABI.



KEY POINTS

- Constraint induced movement therapy may improve function and use of the affected upper limb post ABI.

Hand Splinting and Stretching

The purpose of hand splinting following an ABI is to prevent contractures and deformities, and to reduce spasticity. There are biomechanical and neurophysiologic rationales for splinting the spastic hand (Lannin et al., 2003); the biomechanical approach attempts to prevent contractures by physically preventing shortening of muscle and connective tissues. Conversely, the neurophysiologic approach is based on the concept that the splint can inhibit reflexive contraction of the muscle. Ultimately, the aim is to reduce deformity and contractures in the hand (Table 5), two studies meeting inclusion are discussed below.

TABLE 5 | Hand Splinting and Stretching for Upper Extremity Rehabilitation Post ABI

Author, Year Country Study Design Sample Size	Methods	Outcome
<p>Thibaut et al. (2015) Belgium RCT PEDro=4 N=17</p>	<p>Population: TBI=7, Anoxia=5, Aneurysm=5; Mean Age=41yr; Gender: Male=9, Female=8; Mean Time Post Injury=35mo; Severity: Severe. Intervention: Participants were randomized to receive one of the following exercise protocols on each of their upper limbs: manual stretching and control (no Intervention) (G1, n=8), soft splinting and control (G2, n=12), or soft splinting and manual stretching (G3, n=14). Each exercise was done for 30min followed by a 60min break. Outcomes were assessed before (T1) and after (T2) each protocol, and after each break (T3). Outcome Measures: Modified Ashworth Scale (MAS), Modified Tardieu Scale (MTS), Range of Motion (ROM), and Hand Opening (HO).</p>	<ol style="list-style-type: none"> In G1, there were no significant changes in MAS, MTS, ROM, or HO after stretching or after the control protocol. In G2, the mean MAS score of flinger flexor muscles improved significantly after splinting from T1 to T2 (p=0.014) and the improvement was maintained at T3 (p=0.022). There was no significant change for the control. In G3, the mean MAS score of finger flexor muscles improved significantly after both splinting (p=0.014) and stretching (p=0.022) from T1 to T2, but neither improvement was maintained at T3. In G2, the mean HO score improved significantly after splinting from T1 to T2 (p=0.009), but the improvement was not maintained at T3. There was no significant change for the control. In G3, the mean HO score improved significantly after splinting (p=0.005) from T1 to T2, but the improvement was not maintained at T3. There was no significant change in mean HO score after stretching (p=0.249). In G3 and G2, there were no significant changes in MTS or ROM after the interventions.
<p>Lannin et al. (2003) Australia RCT PEDro=8 N=28</p>	<p>Population: ABI; Gender: Male=13, Female=15. <i>Experimental Group (n=17):</i> Mean Age=65yr; Mean Time Post Injury=47 days. <i>Control Group (n=11):</i> Mean Age=68yr; Mean Time Post Injury=57d. Intervention: The experimental group wore an immobilizing hand splint in a functional position (10°-30° wrist extension) for 4wk, for no longer than 12hr each night. The control group received standard care (motor training and stretching).</p>	<ol style="list-style-type: none"> Effects of splinting were not statistically significant. Splinting increased wrist extension by a mean of 1° post intervention and reduced wrist extension by a mean of 2° at follow-up. Splinting decreased upper-limb function after intervention (MAS; mean 0.3 points) and at follow-up (mean 0.8 points). Splinting decreased performance of hand movements by a mean of 0.4 points (MAS) post intervention and 0.5 points at follow-up.

Author, Year Country Study Design Sample Size	Methods	Outcome
	<p>Outcome Measure: Length of wrist and finger flexor muscles, Hand and arm function, and Visual Analog Scale for Pain (VAS), and Motor Assessment Scale (MAS).</p>	<p>5. Splinting decreased overall upper-limb function by 0.1 points after intervention and by 0.2 points at follow-up (MAS). Increased reported intensity of upper-limb pain (mean: 0.2cm) on VAS after intervention and by 1cm at follow-up.</p>

Discussion

One study evaluated the effect of nighttime hand splinting in conjunction with conventional therapy compared to therapy alone (Lannin et al., 2003). Overall, the results did not demonstrate significant benefits of nocturnal hand splinting. A second randomized controlled trial (RCT) compared manual stretching, soft hand splinting, and manual stretching plus soft hand splinting to determine the optimal intervention (Thibaut et al., 2015). Results suggested that soft hand splinting for 30 minutes resulted in improved hand opening and reduced spasticity of the flexor finger muscles, however, improvements in hand opening were not maintained after the break period. The hand splint was said to be feasible to use in daily care, as the splint was comfortable and easy to apply. There is a need to further research the effect of splinting in individuals with ABI as this practice is used in both acute and rehabilitation settings.

Conclusions

There is level 1b evidence (from one randomized controlled trial; Lannin et al., 2003) that nocturnal hand splinting may not improve upper extremity range of motion or function compared to standard care in individuals post ABI.

There is level 1b evidence (from one randomized controlled trial; Thibaut et al., 2015) that soft hand splinting, but not manual therapy, may improve hand opening in individuals post ABI.



KEY POINTS

- Overnight hand splinting may not improve upper limb function post ABI.
- Soft hand splinting, but not manual therapy, may be beneficial for improving hand opening post ABI.

Interventions for Fine Motor Coordination

As discussed previously, the negative symptoms of UMNS, independent of spasticity, include: weakness, slowness of movement, and loss of finger dexterity (Mayer, 1997). Although gross motor function may return early in the recovery period following an ABI, fine motor deficits may persist and present a considerable challenge for both the individual and the clinicians treating them. The following studies

highlight some of the treatment modalities that are being utilized to improve fine motor ability post ABI (Table 6).

TABLE 6 | Interventions for Fine Motor Rehabilitation Post ABI

Author, Year Country Study Design Sample Size	Methods	Outcome
<p>Neistadt (1994) USA RCT PEDro=5 N=45</p>	<p>Population: TBI=42, Anoxia=3; Mean Age=33.2yr; Gender: Male=45, Female=0, Mean Time Post Injury=7.9yr. Intervention: Participants were assigned to either the parquetry block assembly (n=22) or the meal preparation group (n=23). Participants received individual training sessions (3, 30 min sessions for 6wk) in addition to their regular program. Outcome Measure: WAIS-R (Block Design Test), Parquetry Block Test, RKE-R, and Jebsen-Taylor Test of Hand Function.</p>	<ol style="list-style-type: none"> 1. For picking up small objects with the dominant hand, the meal preparation group showed a significantly greater improvement over the puzzle group (p=0.027). 2. There was no significant difference in improvement between the two groups for simulated page turning with dominant hand (p=0.655), simulated page turning with the non-dominant hand (p=0.182) and picking up small objects with the non-dominant hand (p=0.265).
<p>Korman et al. (2018) Belgium PCT N=20</p>	<p>Population: <i>Experimental Group (N=10):</i> Mean age=30yr; Mean time post-injury=126.9d; GCS range: 3-12. <i>Control Group (N=10):</i> Mean age=29.3yr; Mean time post-injury=118.4d; GCS range: 3-8. Intervention: Individuals were either trained or not trained to complete a 5-finger sequence task. Training took place every day for five days, with approximately 100 sequence repetitions in each practice. Assessment occurred pre-intervention, post-intervention, and at 1-month follow-up. Outcome Measures: Number of correct and incorrect completed sequences during testing.</p>	<ol style="list-style-type: none"> 1. There were no significant differences between groups in performance on the sequence task before the intervention occurred. 2. The trained group showed a significant improvement over the course of training for performance speed (p<0.001), as did the control group (p<0.001). 3. There were no significant differences in the number of errors produces before the intervention compared to post-intervention for either group. 4. The trained group had significantly greater spontaneous gains over the course of the study (p=0.016). Within session gains became negative over the course of the week with performance degrading closer to the end of training sessions (p<0.05). Between session gains steadily improved over the course of training (p<0.05).

Author, Year Country Study Design Sample Size	Methods	Outcome
<p>Yungher & Craelius (2012)</p> <p>USA PCT N=19</p>	<p>Population: TBI=8, Stroke=4, Healthy Participants=7; <i>Experimental Group (n=12):</i> Mean Age=39.8yr; Gender: male=8, female=4. <i>Healthy Control Group (n=7):</i> Mean Age=46.4yr.</p> <p>Intervention: The use of Gesture Recognition Biofeedback (GRB), which uses surface muscle pressures of the forearm to provide real-time visual biofeedback, was compared to standard repetitive training without feedback. Measures were completed before and after each condition.</p> <p>Outcome Measure: Nine-hole peg test (HPT).</p>	<ol style="list-style-type: none"> HPT scores for the experimental group ranged from 28.6 to 263 sec, and 15.78 to 25.56 sec for the control group. For those with impairments (n=12), in training with feedback there was an average decrease in HPT time to completion of 15.5%, and with no feedback there was an increase in time by 2.07%. For those with impairments, GRB training resulted in an improvement of 27.3% (p<0.05), without the GRB training there was a 2.07% decline in performance. In the controls, GRB training has minimal effect. The time to completion was faster in this group, compared to the impaired group, at baseline, and with and without feedback (p<0.05).
<p>Kriz et al. (1995)</p> <p>Germany Pre-Post N=27</p>	<p>Population: TBI=3, Stroke=2, Intracerebral bleeding=3, Viral Encephalitis=1, Cerebral Abscess=1, Healthy Controls=17. Gender: Male=17. Female=10; <i>Impaired Group (n=10):</i> Mean Age=33.8yr; Mean Time Post Injury=14.7mo. <i>Healthy Control group (n=17):</i> Age Range=22-42yr.</p> <p>Intervention: Patients completed a feedback-based training intervention that involved tracking moving targets with grip force, using a precision grip. Patients trained over 10 weekly 30 min sessions. Training terminated when normal performance was achieved.</p> <p>Outcome Measure: Force control using grip strength, Tracking errors, and Transfers.</p>	<ol style="list-style-type: none"> No significant change in control participant's performance (p>0.10). Nine of 10 participants with impairments reduced tracking errors significantly (p<0.05) and improved in transfer tasks (p<0.05). Impaired initial performance and improvement was not uniform and could be attributed to individual aspects of force control.

Discussion

Neistadt (1994) examined fine motor coordination in a group of adult men with TBIs after two types of coordination retraining activities: tabletop activities (i.e., peg board activities, puzzles etc.) and functional activities (i.e., meal preparation). The study results suggested that functional activities may be more effective than tabletop activities in promoting fine motor coordination in persons with brain injury, as indicated by the improvement in “picking up small objects with the dominant hand” that the meal preparation group experienced (Neistadt, 1994). Another study found that visual feedback-based training of grip force is beneficial for individuals post brain injury (Kriz et al., 1995). More specifically, a light-weight force transducer was held between the pulp of index finger and thumb of the impaired hand. In response to visual cues delivered via computer monitor, all tasks involved the gradual increase

and decrease of grip force in training and transfer protocols. Regardless of the individual pattern of impairments, all but one patient succeeded in improving their tracking performance and transferring regained capabilities to other tasks (Kriz et al., 1995).

Another fine motor coordination study compared the use of gesture recognition biofeedback to standard repetitive training without feedback (Yungher & Craelius, 2012). The results from the study showed a significant decrease in task completion time for those who received feedback, in comparison to those who did not. This intervention is both simple to execute (e.g., no precise placement of sensors, etc.) and the assessment is straightforward. The authors suggest that this intervention leads to improvements in fine motor function of the hand with minimal supervision (Yungher & Craelius, 2012). Despite these studies, there is limited evidence to guide clinical practice in this area.

Korman et al. (2018) has found that finger-sequencing tasks may not be effective for improving fine motor compared to the effects of spontaneous recovery. Individuals were either trained or not trained on a finger sequencing task, ultimately there were no significant differences in error rates between groups, although the trained group did significantly improve their performance speed without increasing their error rate (Korman et al., 2018).

Conclusions

There is level 2 evidence (from one randomized controlled trial; Neistadt, 1994) that functional retraining activities may be more effective than tabletop fine motor control retraining activities for improving fine motor function in the dominant hand in individuals post ABI.

There is level 2 evidence (from one prospective controlled trial; Korman et al., 2018) that finger sequencing training may increase performance speed on this task, but not significantly improve error rates in individuals post ABI.

There is level 4 evidence (from one pre-post; Kriz et al., 1995) that visual feedback-based grip force training may improve tracking accuracy and transfer tasks in individuals post ABI.

There is level 2 evidence (from one prospective controlled trial; Yungher & Craelius, 2012) that gesture recognition biofeedback may improve fine motor function compared to standard repetitive training without feedback in individuals post ABI.



KEY POINTS

- **Functional dexterity tasks may be superior to tabletop fine motor control activities for improving fine motor coordination post ABI.**
- **Gesture recognition biofeedback and visual feedback-based training may improve fine motor function post ABI.**
- **Finger sequencing tasks may improve fine motor performance speeds, but not error rates.**

Virtual Reality for Upper Extremity Rehabilitation

With the advancement of technology, virtual reality is now a viable motor rehabilitation intervention for individuals following an ABI. Two studies meeting our inclusion criteria have examined virtual reality interventions for upper extremity motor rehabilitation in ABI populations (Table 7).

TABLE 7 | Virtual Reality Interventions for the Rehabilitation of Upper Extremities

Author Year Country Study Design Sample Size	Methods	Outcome
<p>Mumford et al. (2012) Australia Pre-Post N=9</p>	<p>Population: Severe TBI; Mean Age=30.9yr; Gender: Male=5, Female=4; Mean Time Post Injury=33.8mo. Intervention: Participants had two pre-intervention assessments (4wk apart), then received the Virtual Reality (VR) intervention, followed by a follow-up assessment. The intervention consisted of 12, 1-hr training sessions with the Elements virtual reality system (VR therapy, tracking camera, and tangible working LCD surface), over 4wk in addition to their usual care. Outcome measure: System-measured variables, Box and Block Test (BBT), McCarron Assessment of Neuromuscular Dysfunction (MAND), Neurobehavioural Functioning Inventory (NFI).</p>	<ol style="list-style-type: none"> 1. The intervention provided significant improvements on accuracy percentage for both left (46.26 to 64.25; p=0.01) and right hand (56.86 to 73.62; p=0.02). 2. No significant changes were seen from pre to post treatment on left hand speed, but there was for right hands (0.23m/s to 0.31m/s; p=0.01). 3. Efficiency scores improved significantly only for the right hands (92.61 to 97.68; p=0.002). 4. BBT showed significant improvements from pre to post test for both the left (30.44 to 35.98; p=0.04) and right (46.66 to 53.33; p=0.007) hands. 5. No significant improvements were noted on the MAND. 6. From pre to post treatment, significant improvements in total NFI scores were demonstrated with a reduction from 128.67 to 112.89 (p=0.005), however in each subscale, only the memory/attention subscale improved significantly (p=0.049).
<p>Sietsema et al. (1993) USA PCT N=20</p>	<p>Population: TBI; Mean Age=31.6yr; Gender: Male=17, Female=3; Mean Time Post Injury=6yr. Intervention: Two interventions were compared: An Occupational Embedded Intervention and rote exercise. The occupational embedded intervention involved leaning forward and reaching out the affected arm to play a computer-controlled game. The rote exercise involved leaning forward and reaching out the affected arm on command. Each participant had two 20min sessions, separated by 1wk. Outcome Measure: Range of motion (trunk inclination, shoulder flexion, elbow extension), Total Movement (leaning forward and reaching).</p>	<ol style="list-style-type: none"> 1. There were no significant order effects. 2. There was a significant increase in range of motion concerning hip to wrist movement in the occupational embedded condition compared with the rote exercise group (mean reach length 71.60 cm versus 59.38 cm, p<0.001). 3. The occupational embedded group had a range of motion for scapula-to-wrist that was a mean of 3.52cm greater than the rote exercise group; however, this was not statistically significant.

Discussion

Mumford et al. (2012) used virtual reality therapy with an interactive LCD surface and tracking cameras over 12 1-hour sessions. The authors found that accuracy and dexterity improved significantly in both upper extremities, but speed and efficiency only improved significantly for the right arms of patients.

Sietsema et al. (1993) reported that individuals who used a computer-controlled game aimed at improving reaching had better range of motion in the hip and wrist than individuals who completed rote exercise. Despite the study being performed in 1993, the game used by Sietsema et al. (1993) is still available for use.

Conclusions

There is level 2 evidence (from one prospective controlled trial; Sietsema et al., 1993) and level 4 evidence (from one pre-post; Mumford et al., 2012) that virtual reality training may improve dexterity as well as reaching accuracy and movements post ABI.



KEY POINTS

- **Virtual reality interventions may be an effective intervention for the recovery of upper extremity function post ABI.**

Lower Extremity Interventions

Outcomes targeted by lower extremity interventions following ABI tend to be gait and balance related. Gait improvement can be beneficial for re-establishing independence post ABI. Current methods being used for lower extremity rehabilitation include — but are not limited to — casting, orthosis, and partial body weight supported gait training. Unfortunately, it has been shown that individuals with a brain injury can begin to develop lower extremity contractures within the first few months of injury (Baagoe et al., 2018).

Partial Body Weight Supported Gait Training

Movement disorders post ABI decrease the independence of a person due to loss of ambulation. The inability to maintain an erect posture, due to a lack of sufficient strength and balance, may prevent the training necessary for the restoration of self-ambulation following brain injury. Partial body weight supported gait training is postulated to result in earlier gait rehabilitation and earlier weight-bearing to increase strength and reduce spasticity. Additionally, this gait intervention allows for the simulation of task-specific walking movements and enables rehabilitation therapists to assist patients in the components of gait, rather than focusing on bearing the patient's body weight. This type of gait training physically supports patients in a way that does not generate compensatory ambulation strategies that may develop while using a cane or a walker (Seif-Naraghi & Herman, 1999). In addition, partial body

weight support reduces the demands on muscles while the patient works on improving the coordination of the movement. Body weight support can be gradually adjusted, as the patient improves, to encourage postural control and balance (Table 8).

TABLE 8 | Partial Body Weight Supported Gait Training for Lower Extremity Rehabilitation Post ABI

Author Year Country Study Design Sample Size	Methods	Outcome
<p>Esquenazi et al. (2013) USA RCT PEDro=4 N=16</p>	<p>Population: TBI; Gender: Male=7, Female=9. Robotic-Assisted Group (n=8): Mean Age=37.1yr; Mean Time Post Injury=140.3mo. Manually Assisted Group (n=8): Mean Age=41.9yr; Mean Time Post Injury=150.4mo. Intervention: All participants received gait training for 45min, 3 x/wk for a total of 18 sessions. The training was either Robotic-Assisted Treadmill Training (RATT) or Manually Assisted Treadmill Training (MATT). Outcome Measure: Over ground walking Self-Selected Velocity (SSV), Maximal Velocity, Spatiotemporal Symmetry, 6-minute Walk Test (6MWT), and Stroke Impact Scale.</p>	<ol style="list-style-type: none"> For the RATT group, SSV increased by 49.8% (p=0.01), maximal velocity by 14.9% (p=0.01), step length asymmetry ratio improved during SSV by 33.1% (p=0.01), and the 6MWT improved by 11.7% (p=0.21). For the MATT group, SSV increased by 31% (p=0.06), maximal velocity increased 30.8% (p=0.01), step-length asymmetry ratio improved during SSV by 9.1% (p=0.73), and the 6MWT improved by 19.3% (p=0.03). No significant between group differences were found for any of the outcome measures.
<p>Wilson et al. (2006) USA RCT PEDro=7 N=38</p>	<p>Population: TBI; Mean Age=29.6yr; Gender: Male=35, Female=3; Mean Time Post Injury: Experimental Group (n=19) =4mo, Control Group (n=19)=2.8mo. Intervention: Patients in the control group received standard physical therapy for 8wk. The experimental group had physical therapy supplemented with partial weight-bearing gait training twice weekly. Outcome Measure: Functional Independence Measure and Functional Assessment Measure (FIM+FAM), Rivermead Mobility Index (RMI), Gross Motor Subscale (GMS), Standing Balance Scale (SBC), Functional Ambulation Category (FAC).</p>	<ol style="list-style-type: none"> The control group had significant improvements on the SBC (p<0.0039), FAC (p<0.0002), RMI (p<0.0001), GMS (p<0.0005), and FIM+FAM (p<0.0002). The experimental group had significant improvements on the SBC (p<0.002), FAC (p<0.0002), RMI (p<0.0009), GMS (p<0.0015), and FIM+FAM (p<0.0039). No between group differences were found for the SBC, FAC, RMI, GMS, or the FIM+FAM.
<p>Brown et al. (2005) USA RCT PEDro=5 N=20</p>	<p>Population: TBI; Mean Age=40.2yr; Gender: Male=14, Female=6; Mean Time Post Injury=15.8yr. Intervention: Patients received either Body Weight Support Treadmill Training (BWSTT; n=10) or conventional over-ground gait training (COGT; n=9) for 15 min plus 30 min of exercise 2 days/wk for 3 mo. Outcome Measure: Functional Ambulation Category, Functional Reach, Timed Up and Go, Gait velocity, Stride Width, Left-Right Step Length differential.</p>	<ol style="list-style-type: none"> Step Length Differential improved significantly more for the COGT group than for the BWSTT group after 3mo of intervention (p=0.011). There were no other significant differences between groups at baseline or after 3mo of intervention for any of the outcome measures.

Discussion

Brown et al. (2005) conducted a RCT in which 20 patients with ABI were randomized to either body weight supported treadmill training or conventional over-ground gait training. The authors reported that body weight supported treadmill training provided no additional benefit over conventional gait training

in measures of ambulation following three months of training. However, it was noted that conventional gait training improved Step Length Differential significantly more than the body weight supported treadmill training. Similarly, in another RCT, Wilson et al. (2006) randomized 40 patients with ABI to either standard physical therapy or physical therapy supplemented with partial body weight-bearing gait training. The authors also reported that although each group made functional improvements, there were no significant between-group differences on measures of balance, ambulation, and mobility at the end of the eight-week training period (Wilson et al., 2006). Once again, Esquenazi et al. (2013) compared robotic assisted treadmill training to manually assisted treadmill training for individuals with TBI. The researchers noted that while both interventions resulted in significant improvement in gait parameters, there were no differences between the two interventions for gait velocity, endurance, or mobility. From these studies, it appears that body weight supported gait training is not superior to more conventional methods.

Conclusions

There is level 2 evidence (from one randomized controlled trial; Brown et al., 2005) that body weight supported treadmill training may not improve ambulation or mobility compared to conventional gait training in individuals post ABI.

There is level 1b evidence (from one randomized controlled trial; Wilson et al., 2006) that physical therapy with partial weight-bearing gait training may not improve ambulation, mobility, or balance compared to standard physical therapy in individuals post ABI.

There is level 2 evidence (from one randomized controlled trial; Esquenazi et al., 2013) that robotic assisted body weight supported treadmill training may not improve ambulation or gait velocity compared to manually assisted treadmill training in individuals post ABI.



KEY POINTS

- **Partial body weight supported gait training likely does not improve ambulation, mobility, or balance when compared to conventional gait training post ABI.**
- **Robotic assisted treadmill training may be similar to manually assisted treadmill training at improving gait speed and mobility post ABI.**

Multimodal Interventions

Multimodal interventions provide an opportunity to compare or combine interventions to better evaluate rehabilitation options. Combining interventions allows multiple physical impairments to be targeted in a single program, while comparing them assists in determining the relative effect of each therapy for motor rehabilitation (Table 9).

TABLE 9 | Multimodal Interventions for Lower Extremity Rehabilitation Post ABI

Author Year Country Study Design Sample Size	Methods	Outcome
<p>Clark et al. (2012) Australia RCT PEDro=3 N=42</p>	<p>Population: <i>Experimental Group (n=17):</i> TBI=11, Stroke=5, Multiple Sclerosis=1; Mean Age=38.7yr; Gender: Male=10, Female=7; Median Time Post Injury=9 mo. <i>Control Group (n=25):</i> Healthy controls; Mean Age=27.8yr; Gender: Male=16, Female=9.</p> <p>Intervention: All participants performed 7 alternative gait training methods in a randomized order. Methods included: therapist manual facilitation, use of gait assistive device, treadmill walking with handrail support, and 4 variations of body weight-support treadmill training with combinations of handrail and/or therapist support.</p> <p>Outcome Measure: Mediolateral Center of Mass Movement, Stride Time, Stability of Movement.</p>	<ol style="list-style-type: none"> 1. Body weight-support treadmill training without any additional support resulted in greater amplitude, altered timing, and reduced movement stability compared with non-pathologic gait. 2. Manual facilitation by the therapist most closely matched non-pathologic gait for timing and stability. 3. The use of therapist facilitation or handrail support reduced the effect and resulted in treadmill training having lower movement amplitudes when compared to other methods of training.
<p>Canning et al. (2003) Australia RCT PEDro=7 N=22</p>	<p>Population: Severe TBI; Gender: Male=16, Female=6. <i>Experimental Group (n=12):</i> Mean Age=24.75yr; Mean Time Post Injury=75.25d. <i>Control Group (n=10):</i> Mean Age=25.6yr; Mean Time Post Injury=84.6d.</p> <p>Intervention: Patients were divided randomly into either a regular rehabilitation program group (control) group or the intervention group which received the rehabilitation program as well as 4wk of intensive training of sit-to-stand and step-up exercises.</p> <p>Outcome Measure: Sit-to-stand repetitions, Peak Oxygen Consumption (exercise capacity), Oxygen Consumption Workload Test (exercise efficiency).</p>	<ol style="list-style-type: none"> 1. The experimental group performed a mean of 87 repetitions of sit-to-stand and 42 repetitions of step-ups per working day. 2. The intervention group had a 62% improvement in the number of sit-to-stands performed in 3min (motor performance) compared to 18% increase in the control group (p=0.03). 3. There were no significant between-group differences in the improvements made in exercise capacity (p=0.36) or efficiency (p=0.38). 4. The increase in exercise capacity for the intervention group was significant with an increase in VO₂peak from 0.75L/min to 1.14L/min (p<0.01).
<p>Peters et al. (2014) USA Pre-Post N=10</p>	<p>Population: TBI; Median Age=35.4yr; Gender: Male=6, Female=2; Median Time Post Injury=9.9yr.</p> <p>Intervention: Participants went through 20 days of intensive mobility training (5 d/wk for 4wk). Sessions included gait training with body-weight-supported treadmill, balance activities, strength coordination, and range of motion training.</p> <p>Outcome Measure: Berg Balance Scale, Dynamic Gait Index (DGI), 10 Metre Walk Test (10MWT), 6 Minute Walk Test (6MWT), 30 sec Sit-to-Stand test, Timed Up and Go (TUG) test, Walking While Talking Test average errors/ alternating letters, Falls Efficacy Scale (FES), Quality of Life after Brain Injury, Global Rate of Change Scale, Fatigue.</p>	<ol style="list-style-type: none"> 1. The average session was 150.1±2.7min. 2. Fatigue scores ranged from 0 to 2.5 (out of 10) before sessions and 3 to 5.5 after. 3. From pre-test to post-test, significant improvements were seen for the FES (p=0.01), DGI (p=0.049), 10MWT (p=0.03), TUG (p=0.01), and 6MWT (p=0.03). 4. From pre-test to follow-up (3mo), significant improvements were sustained for the 10MWT (p=0.02) and the TUG (p=0.03).

Author Year Country Study Design Sample Size	Methods	Outcome
Hirose et al. (2013) Japan PCT N=15	<p>Population: TBI=8, Stroke=7; Gender: Male=11, Female=4. <i>Control Group (n=6):</i> Mean Age=59.8yr. <i>Intervention Group (n=9):</i> Mean Age=49.9yr.</p> <p>Intervention: The control group received passive exercise and the intervention group received Electrical Muscle Stimulation (EMS) weekly (30min with stimulation cycles of 10 sec) in addition to passive exercise for 6wk.</p> <p>Outcome measure: Rate of Atrophy.</p>	<ol style="list-style-type: none"> 1. There was a significant difference in the rate of atrophy between the EMS and control group, the EMS group showing less, in all 4 compartments (anterior and posterior thigh and leg) at day 14 (p<0.001). 2. At 6wk the cross-sectional area was examined again, showing a significant difference between groups, with the EMS group showing less atrophy. (p<0.001).
Williams et al. (2019) Australia PCT N _{Initial} =22, N _{Final} =22	<p>Population: TBI=12; Mean Age=25.5±10.7yr; Gender: Male=10, Female=2; Mean Time Post Injury=374±486d; Severity: Mean PTA=57.8±25.9d.</p> <p>Intervention: Healthy participants and individual with TBI completed a 6mo rehabilitation program focused on functional ballistic activities and task-specific practice to compare lower-limb joint mechanics during running. Outcome measures were assessed at baseline and 6mo follow-up.</p> <p>Outcome Measures: Average power absorbed and generated at the hip, knee, and ankle joints during stance.</p>	<ol style="list-style-type: none"> 1. When compared to healthy controls, those with TBI ran with greater average power absorption at the hip (-.27W/kg versus -61W/kg; p<.05), reduced average power absorption at the knee (-2.03W/kg versus -1.02W/kg; p<.05) and reduced average power generation at the ankle (2.86W/kg versus 2.06W/kg; p<.05). 2. Only average power generation at the ankle improved following six months of rehabilitation for the participants with TBI (2.06W/kg versus 2.79W/kg; p<.05).

Discussion

Canning et al. (2003) in a single blinded RCT compared the addition of an intensive sit-to-stand training program to a traditional rehabilitation program. The experimental group demonstrated an increased ability to repeat sit-to-stand within a defined time frame in comparison to the traditional rehabilitation group, however there were no differences between groups in the increase of exercise capacity or efficiency. Hirose et al. (2013) used passive exercise as a control and compared it with electrical muscle stimulation (EMS) to determine the effects of EMS on muscle atrophy in the lower limbs. The use of EMS resulted in significantly reduced amounts of atrophy when compared to passive exercise.

Clark et al. (2012) demonstrated that using body-weight-support treadmill training with handrail support reduces the amount of center of mass displacement and movement instability. However, they also noted that support alters timing and variability components of gait patterns. Although the study explored seven gait training methods, Clark et al. (2012) concluded that no one method provides the optimal stimulus and that combining various methods may be the most beneficial. Peters et al. (2014) identified that with intensive therapy using body-weight-support treadmill training, balance activities, strength coordination, and range of motion activities, individuals can significantly improve their walking speed and Timed Up and Go test scores. The benefits lasted up to three months post intervention.

A prospective controlled trial investigated the efficacy of a six-month rehabilitation program focusing on functional ballistic activities and task-specific practice on deficits identified in biomechanical variables during running (Williams & Schache, 2019). It was found that the average power generation at the ankle improved for the participants with TBI following the intervention period. The authors further noted that compared to healthy controls, participants with TBI ran with greater average power absorption at the hip, reduced average power absorption at the knee, as well as reduced average power generation at the ankle (Williams & Schache, 2019).

Conclusions

There is level 2 evidence (from one randomized controlled trial; Clark et al., 2012) that body-weight-support treadmill with handrail support may reduce movement instability compared to other methods of training in individuals post ABI.

There is level 1b evidence (from one randomized controlled trial; Canning et al., 2003) that sit-to-stand training combined with usual rehabilitation may improve motor performance in sit-to-stand tasks compared to usual rehabilitation alone in individuals post ABI.

There is level 2 evidence (from one prospective controlled trial; Hirose et al., 2013) that electrical muscle stimulation with passive exercise may reduce lower extremity muscle atrophy compared to passive exercise in individuals post ABI.

There is level 4 evidence (from one pre-post; Peters et al., 2014) that Intensive Mobility Training may improve ambulation and mobility in individuals post ABI.

There is level 2 evidence (from one prospective controlled trial; Williams et al., 2019) that motor rehabilitation may improve high-level mobility and ankle joint mechanisms during running in individuals with severe TBI.

KEY POINTS

- **Electrical muscle stimulation with passive exercise may improve lower extremity muscle atrophy post ABI.**
- **Sit-to-stand training and Intensive Mobility Training may improve lower extremity motor function post ABI.**
- **Motor rehabilitation may improve high-level mobility and ankle joint mechanisms during running in individuals with severe TBI**
- **Body-weight-support treadmill with handrail support may reduce movement instability compared to other methods of training in individuals post ABI.**

Virtual Reality for Lower Extremity Rehabilitation

In addition to providing support for the rehabilitation of upper extremity function, virtual reality interventions have also been used to examine their efficacy on lower extremity remediation.

TABLE 10 | Virtual Reality Interventions for Lower Extremity Post ABI

Author Year Country Study Design Sample Size	Methods	Outcome
<p>Cuthbert et al. (2014) USA RCT PEDro=6 N=20</p>	<p>Population: TBI; Gender: Male=13, Female=7; Range of Time Post Injury=24-122d. Intervention: Participants were randomly assigned to either Extra Standard Balance Care (ESC; n=10) (standard physical therapy) or Virtual Reality (VR) balance therapy (n=10) using the Nintendo Wii. Both groups received standard physical therapy 4x/wk. The ESC group had an additional 15min of balance-specific therapy and the VR therapy group had 15min of balance training using the Wii Fit. Outcome Measure: Physical Activity Enjoyment Scale (PACES), Berg Balance Scale (BBS), Functional Gait Assessment (FGA).</p>	<ol style="list-style-type: none"> 1. There was no statistically significant difference between therapy groups on PACES scores at mid-treatment (p=0.59) or at treatment completion (p=0.34). 2. The VR therapy group had a significant improvement on the BBS over time (0.19 points per day, p=0.03); however, there were no significant between group differences (VR therapy had a 1.13-point higher improvement than the ESC group, p=0.70). 3. Within group improvements were found on the FGA (ESC=0.20, p=0.01 and VR therapy=0.23, p<0.01); however, there were no statistically significant differences found between groups (p=0.73).
<p>Foo et al. (2013) Australia Post-Test N=20</p>	<p>Population: TBI=11, Tumour=3, Stroke=2, Cerebral Palsy=2, SCI=1, Anoxic Brain Injury=1; Mean Age=43.3yr; Mean Time Post Injury=23.3mo. Intervention: Participants completed two tasks (static standing and sit-to-stand) three times each, with and without visual feedback. Feedback was provided using the Wii Balance Board. Outcome measure: Weight-bearing Asymmetry.</p>	<ol style="list-style-type: none"> 1. During the static balance task, weight-bearing asymmetry was significantly reduced with visual feedback (p=0.005). 1. There was no significant difference with visual feedback for the dynamic test (p=0.737); however, those with higher weight-bearing asymmetry were the most responsive to feedback.

Discussion

Cuthbert et al. (2014) also demonstrated a significant within-group improvement on balance using virtual reality-based therapy; however, the gains made using this intervention were not significantly different compared to participants receiving standard physical therapy. Finally, during static balance tasks, visual feedback provided using a Wii Balance board helped reduce weight-bearing asymmetry (Foo et al., 2013).

Conclusions

There is level 1b evidence (from one randomized controlled trial; Cuthbert et al., 2014) that virtual reality training compared to balance training may not be more effective for improving lower extremity function post ABI. However, virtual reality training was shown to improve function independently.

There is level 4 evidence (from one post-test; Foo et al., 2013) that visual feedback may reduce weight-bearing asymmetry in the lower extremities post ABI.



KEY POINTS

- Virtual reality can be used for the remediation of motor function in the lower extremities post ABI.

Combined Upper and Lower Extremity Interventions

Unlike the studies referenced above, some programs combine interventions that treat both the upper and lower extremities. One of the challenges with combined rehabilitation is the choice of testing method. With a larger range of potential outcomes, it can be difficult to choose the proper test to evaluate the effect of the intervention.

Virtual Reality

Virtual reality training has been gaining popularity over time. The advancement of virtual reality treatments has partly been influenced by commercial availability of programs, such as the Wii Fit Balance Board, that provide reliable testing and virtual reality games (Foo et al., 2013). Despite the increasing availability of virtual reality programs, there are a limited number of studies evaluating their efficacy (Table 11).

TABLE 11 | Virtual Reality Interventions for Upper and Lower Motor Rehabilitation Post ABI

Author Year Country Study Design Sample Size	Methods	Outcome
Ustinova et al. (2014) USA Pre-Post N=30	<p>Population: TBI; Mean Age=30.6yr; Gender: Male=10, Female=5; Mean Time Post Injury=6.1yr.</p> <p>Intervention: Participants had completed physical therapy previously and had reached a plateau. All participants received virtual reality (VR) therapy which was a series of VR games that re-trained whole-body coordination, posture, and gait. All games allowed for</p>	<ol style="list-style-type: none"> 1. BBS scores increased by a mean of 4.5 points (45.6±5.15 to 50.2±4.4, p<0.01). 2. FGA scores improved by a mean of 4.6 points (20.3±5.6 to 24.9±4.6, p<0.05). 3. FRT scores increased by a mean reaching distance of 2.3 inches (12.5±2.3 to 14.8±2.3, p<0.01).

Author Year Country Study Design Sample Size	Methods	Outcome
	advancement into more difficult levels. Therapy was a total of 15 sessions, each 50-55 min (typically 2-3 sessions/wk, over 5-6wk). Outcome Measure: Berg Balance Scale (BBS), Functional Gait Assessment (FGA), Functional Reaching Test (FRT).	
Schafer & Ustinova (2013) USA PCT N=30	Population: TBI=15, Healthy Controls=15. <i>TBI Group (n=15):</i> Mean Age=35.3yr; Gender: Male=6, Female=9; Mean Time Post Injury=6.6 yr; <i>Control Group (n=15):</i> Mean Age=33.4yr; Gender: Male=7, Female=8. Intervention: Participants completed reach activities in a physical environment (PE; reach to the farthest point possible) and a virtual environment (VE; touching furthest flower seen on the screen with hand avatar). VE touches were done from 50° and 10° angles. In each setting, three reaches were completed with the dominant hand. Outcome measure: Centre of Mass (COM) Displacement, Endpoint Displacement Amplitude, Movement Time, Peak Velocity.	<ol style="list-style-type: none"> 1. The control group showed greater endpoint displacement amplitude ($p<0.01$) and COM displacement ($p<0.01$) than the TBI group. 2. Reaches were performed more slowly among participants with TBI, but the difference between groups was not significant ($p>0.05$). 3. Reaching amplitude was ~9% further for both groups in the VE than the PE ($p<0.05$). 4. For both groups, reaches were farther in the PE after performing in the VE. The TBI group increased their reach by ~5% ($p<0.05$).

Discussion

Virtual reality interventions have been shown to be beneficial for improving balance post ABI. Ustinova et al. (2014) had participants complete 15 sessions of virtual reality therapy targeting the recovery of postural and coordination abnormalities and demonstrated significant improvements for balance and dynamic stability following treatment. Schafer and Ustinova (2013) compared reaches in the physical environment after having participants with TBI and controls practice reaches in a virtual environment. Reaching distances in the physical environment increased for both groups, but a greater effect was noted among those with TBI.

Conclusions

There is level 2 evidence (from one pre-post; Ustinova et al., 2014) that virtual reality therapy may improve balance, gait, and functional reaching in individuals post ABI.

There is level 2 evidence (from prospective controlled trial; Schafer & Ustinova, 2013) that activities in a physical environment and a virtual environment improve reaching in individuals with TBI.



KEY POINTS

- Virtual reality training likely improves balance in individuals post ABI, however it may not be more effective than conventional physiotherapy programs.

Exercise Programs

Following an ABI, motor impairments in combination with cognitive impairment can have a significant impact on functional abilities (Boake et al., 2000). Unlike the more uniform focal deficits seen following stroke, the motor deficits following ABI tend to be diverse. These deficits include: impairment of force, endurance, coordination, and balance (Boake et al., 2000). Frequently, rehabilitation efforts are directed at specific motor impairments with the aim of improving overall functional ability.

Aerobic Training

Many patients with ABI have gone through a period of prolonged bed rest as a result of comorbid injuries or a prolonged loss of consciousness; consequently, cardiovascular changes, muscular atrophy, and loss of lean body mass commonly occur (Boake et al., 2000). General fitness training following ABI has the potential to influence multiple outcomes beyond the mere direct physical benefits such as improved aerobic capacity (Bushbacher & Porter, 2000). When comparing individuals with TBI that exercise to those that do not, the exercisers were less depressed, had less symptoms overall, and better self-reported health status than non-exercising brain injury survivors (Gordon et al., 1998). The following studies examined the effectiveness of aerobic training on motor outcomes in individuals with an ABI (Table 12).

TABLE 12 | Aerobic Training for Lower Extremity Rehabilitation Post ABI

Author Year Country Study Design Sample Size	Methods	Outcome
Hassett et al. (2012) Australia RCT PEDro=6 N=40	<p>Population: Severe TBI=40; Experimental Group (n=20): Mean Age=39yr; Gender: Male=14, Female=6; Mean Time Post Injury=3.7mo. Control Group (n=20): Mean Age=29yr; Gender: Male=13, Female=7; Mean Time Post Injury=3.1mo.</p> <p>Intervention: All participants wore a heart rate monitor and attended a 1hr circuit class 3/wk which included 10 workout stations, an abdominal exercise portion and a walk for 6min. The experimental group received encouragement from a physiotherapist and had their heart rate monitor uncovered which beeped when they did not reach their target heart rate. Those in the control group did not receive encouragement and had their heart rate monitor covered and muted.</p> <p>Outcome Measure: Duration of Time spent in Heart Rate Target Zone.</p>	<ol style="list-style-type: none"> All participants achieved a mean of 13+14min in their heart rate target zone and expended >300cals. For the class, the exercise intensity was low (mean heart rate reserve of 34.3+16.7%) but duration of exercise was long (mean of 52.1+3.1min). For time spent in the heart rate target zone, the experimental group (mean 10.9±10.8min) performed better than the control group (mean 6.1±7.5min) but this was not significant (mean difference 4.8min, p>0.05).
Hoffman et al. (2010) USA RCT	<p>Population: TBI; Exercise Group (n=40): Mean Age=39.7yr; Gender: Male=15, Female=25. Control</p>	<ol style="list-style-type: none"> The exercise intervention group reported exercising more days of the week than the control group (3.68 versus 2.05, p=0.004); however, the increase in minutes per week

Author Year Country Study Design Sample Size	Methods	Outcome
<p>PEDro=5 N=80</p>	<p>Group (n=40): Mean Age=37.1yr; Gender: Male=20, Female=20.</p> <p>Intervention: Participants were randomly assigned to the exercise or control group. The 10wk community-based exercise intervention consisted of supervised aerobic exercise (1/wk) involving 30min of aerobic exercise and were instructed to complete aerobic exercise at home (30min, 4x/wk). The control group was waitlisted.</p> <p>Outcome Measure: Borg Scale of Perceived Exertion, Brief Pain Inventory, Beck Depression Inventory (BDI), SF-12 Health Survey (SF-12), Perceived Quality of Life Scale (PQOL), Craig Handicap Assessment and Reporting Technique-Short Form (CHART-SF).</p>	<p>of exercise was not significantly different between groups (p=0.064).</p> <ol style="list-style-type: none"> 2. The exercise group also reported less pain interference (p=0.021) and greater improvement on the Brief Pain Inventory (p=0.031) in comparison to the control group. 3. Post-hoc analyses compared highly active (>90min/wk) and low activity (<90min/wk) participants, regardless of initial grouping. Highly active participants reported significantly more community activity on the CHART-SF (p=0.028), greater PQOL scores (p=0.034) and greater SF-12 general mental health scores (p=0.024) than the low activity group. 4. The highly active group scored lower on the BDI after the 10wk intervention than the low active group (p=0.033).

Author Year Country Study Design Sample Size	Methods	Outcome
<p>Hassett et al. (2009) Australia RCT PEDro=7 N=62</p>	<p>Population: Severe TBI; Fitness Center Group (n=32): Mean Age=35.4 yr; Gender: Male=27, Female=5; Median Time Post Injury=2.6 mo. Home-Based Group (n=30): Mean Age=33 yr; Gender: Male=26, Female=4; Median Time Post Injury=2.3 mo.</p> <p>Intervention: Participants were randomly assigned to either an exercise intervention group at a fitness-center or to a home-based exercise group. Fitness center participants were supervised by a personal trainer (1hr, 3x/wk, 12wk), whereas the home-based exercise group followed an exercise plan prescribed before discharge and were monitored by a physiotherapist. Assessment at baseline, end of intervention and 3mo follow-up.</p> <p>Outcome Measure: Modified 20-metre Shuttle Test (MST), Depression Anxiety Stress Scale, Profile of Mood States (POMS), Sydney Psychosocial Reintegration Scale (SPRS), Brain Injury Community Rehabilitation Outcome.</p> <p>Population: Severe TBI=30; Mean Age=33yr; Gender: Male=26, Female=4; Mean Time Post Injury=2.3mo.</p> <p>Intervention: An in-home exercise program (36 sessions over 12wk) was completed in a previous study. Participants were then retrospectively divided into adherers (n=10) and non-adherers (n=20) and compared.</p> <p>Outcome Measure: Modified 20-metre Shuttle Test, Wechsler Memory Scale III, Wechsler Adult Intelligence Scale III, Controlled Oral Word Association Test, Depression Anxiety and Stress Scale.</p>	<ol style="list-style-type: none"> 1. On average the fitness center group had better adherence than the home-based group (77% versus 44%, $p \leq 0.001$). The fitness center group completed a mean of 2.4 sessions/wk compared to the home group who completed 0.5 sessions/wk. 2. At the end of the program, both groups improved their fitness levels on the MST; however, there were no significant differences between groups ($p > 0.05$). 3. Those in the fitness centre group achieved a significantly greater percentage of goals at the end of the intervention (76% versus 52%, $p = 0.005$), but this difference diminished at follow-up ($p = 0.650$). 4. No significant differences were noted when comparing psychosocial functioning or community integration measures between groups except for the POMS Confusion-Bewilderment ($p = 0.007$) and the SPRS Living Skills ($p = 0.009$) subscales at the end of intervention only, with greater improvements in the fitness center group. <ol style="list-style-type: none"> 1. Non-adherers were significantly younger than adherers (30 versus 39yr, $p = 0.04$). 2. Results indicate that a greater number of participants in the adherence group reported walking or jogging pre-injury compared to non-adherers (7 versus 5, $p \leq 0.05$). 3. A greater portion of adherers had extremely severe injuries compared to non-adherers (90% versus 50%, $p \leq 0.05$). 4. There were no significant differences between groups on any of the cognitive functioning or psychological health measures.
<p>Hassett et al. (2011) Australia RCT follow-up N=30</p>	<p>(This cell is empty in the original image, sharing the text from the previous row)</p>	<p>(This cell is empty in the original image, sharing the text from the previous row)</p>

Author Year Country Study Design Sample Size	Methods	Outcome
<p>Driver et al. (2006) USA RCT PEDro=4 N=18</p>	<p>Population: TBI; Exercise Group (n=9): Mean Age=37.8yr; Gender: Male=5, Female=4; Mean Time Post Injury=40.3 mo. Control Group (n=9): Mean Age=35.5yr; Gender: Male=5, Female=4; Mean Time Post Injury=41.2 mo. Intervention: Participants were randomly assigned to either an 8wk aquatic exercise program involving 1hr sessions 3x/wk consisting of aerobic and resistance training or to a control group that received 8wk of vocational rehabilitation class to improve reading and writing skills. Outcome Measure: Health Promoting Lifestyle Profile II (HPLP-II), Physical Self-Description Questionnaire (PSDQ).</p>	<ol style="list-style-type: none"> 1. The exercise group experienced significant improvements on the health responsibility, physical activity (both p<0.05), nutrition, spiritual growth (both p<0.01), and interpersonal relationships (p<0.001) subscales of the HPLP-II after the intervention, but not the stress management subscale. The control group showed no significant improvements on any the subscales (p>0.05). 2. At the end of the program, the aquatic exercise group showed significant improvements on the self-esteem, coordination, body fat, strength, flexibility, and endurance sub-scales of the PSDQ (all p<0.001). The control group showed no significant improvements. 3. No between-group calculations were completed.
<p>Bateman et al. (2001) UK RCT PEDro=7 N=157</p>	<p>Population: TBI=44, Stroke=70, Subarachnoid Hemorrhage=15, Other=28; Gender: Male=97, Female=60. Training Group (n=79): Mean Age=41.7yr; Mean Time Post Injury=22.2 wk. Control Group (n=79): Mean Age=44.7yr; Mean Time Post Injury=25.5wk. Intervention: Participants were divided into either an exercise intervention (intervention group, cycle training) or relaxation training (control group). The interventions were 30 min sessions, 3x/wk for 12 wk. Outcome Measure: Peak Work Rate, Berg Balance Scale, Rivermead Mobility Index (RMI), Barthel Index, Functional Independence Measure (FIM), Nottingham Extended Activities of Daily Living (NEDLI).</p>	<ol style="list-style-type: none"> 1. The mean increase in peak work rate from baseline to 12wk was 25.8W and 11.7W, for the training and control group, respectively (p=0.02). 2. No significant differences were found between groups on the Berg Balance Scale, RMI, or the Barthel Index. 3. There was a trend towards significance, with the control group making greater improvements on the Berg Balance scale (p=0.06) and RMI (p=0.07) than the training group. 4. Greater FIM gains and improvements on the NEADLI were found for the control group between 12 and 24wk (p<0.05) compared to the training group.
<p>Charrette et al. (2016) USA Pre-Post NInitial=16, NFinal=14</p>	<p>Population: TBI=9, Stroke=3, Tumor=1, Encephalopathy=1; Mean Age=44.8yr; Gender: Male=12, Female=2; Mean Time Post Injury=20.5yr; Injury Severity: Moderate-Severe. Intervention: Participants took part in an intensive exercise program consisting of endurance, full-body strength, stretching, and balance exercises (3d/wk for 6wk). Assessments took place at baseline, 6wk (exercise completion) and 12wk (follow-up). Outcome Measure: 6-Minute Walk Test (6MWT), High Level Mobility Assessment Tool (HiMAT), 10-Metre Walk Test (10MWT).</p>	<ol style="list-style-type: none"> 1. There was a significant increase in distance walked from baseline (431ft) to 6wk (1016ft) and 12wk (712ft) during the 6MWT (p<0.05). 2. There was a significant increase in mobility from baseline (3.5) to 6wk (9) and 12wk (8) on the HiMAT (p<0.05). 3. There was a significant increase in gait velocity from baseline (0.59m/s) to 6wk (1.11m/s) and 12wk (1.10m/s) measured by the 10MWT (p<0.05).

Author Year Country Study Design Sample Size	Methods	Outcome
<p>Damiano et al. (2016) USA Case Control NInitial=31, NFinal=24</p>	<p>Population: TBI=12, Healthy participants=12; TBI group (n=12); Mean Age=31.3yr; Gender: Male=7, Female=5; Time Post Injury>6 mo. Healthy Volunteers (controls; n=12); Mean Age=32.5yr; Gender: Male=7, Female=5.</p> <p>Intervention: Participants with TBI followed a home-based exercise program with an elliptical (30 min 5d/wk for 8wk). Resistance was added progressively each week. Controls did not complete the exercise intervention. Assessments were completed at baseline, 8wk and follow-up.</p> <p>Outcome Measure: Limits of Stability Test (LOS), Motor Control Test (MCT), High-Level Mobility Assessment Tool (HiMAT), Hamilton Depression Inventory (HAM-D), Sensory Organization Test, Gait, Cadence, Dual-Task performance (DT), Hopkins Verbal Learning Test-Revised (HVLT-R), Finger Tapping Test (FTT), Pittsburgh Sleep Quality Index (PSQI), Beck Anxiety Inventory, PTSD Checklist-Civilian Version (PCL-C).</p>	<ol style="list-style-type: none"> 1. There was a significant difference in LOS between the TBI group and controls in 2 directions; backwards (TBI=71.6%, HV=89.3%, p=0.042) and left (TBI=37%, HV=49.6%, p=0.037). 2. The TBI group had a significantly poorer DT performance on both motor (p=0.047) and cognitive (p=0.045) tasks when compared to controls. 3. The TBI group performed significantly worse than controls on HVLT-R (p=0.004), PCL-C (p=0.02) and HAM-D (p=0.04). 4. Within the TBI group, maximal movement during the LOS test had a strong relationship with HVLT-R total recall (r=0.74, p=0.008) and delayed recall (r=0.81, p=0.003) and was related to fewer depressive symptoms (r=-0.63, p=0.04). 5. Within the TBI group, slower walking velocity and slower FTT was related to higher depression scores (r=-0.65, p=0.03 & r=-0.72, p=0.04, respectively). FTT was also related to poorer sleep quality (r=-0.75, p=0.048). 6. Within the TBI group, poorer DT performance was related to higher anxiety (r=0.71, p=0.02). 7. MCT and LOS improved following 8 wk of exercise and did not change at follow-up aside from increased LOS forward endpoint excursion (p=0.001).
<p>Ustinova et al. (2015) USA Pre-Post N=22</p>	<p>Population: TBI; Mean Age=29.2yr; Gender: Male=13, Female=9; Mean Time Post Injury=23.6mo; Mean GCS=11.2.</p> <p>Intervention: Participants completed a therapeutic exercise program supervised by a physical therapist designed for retaining whole-body coordination, posture, and gait. The program included twenty 30-40 min sessions, increasing to 55-60 min as the patient became more comfortable (4-5d/wk for 4-5wk).</p> <p>Outcome Measure: Berg Balance Scale (BBS), Functional Independence Measure (FIM), Functional Gait Assessment (FGA), Ataxia Scale.</p>	<ol style="list-style-type: none"> 1. There was a significant improvement in static and dynamic balance from the pre-test to post-test on the BBS (45.2 versus 49.2, p=0.011). 2. There was a significant improvement in gait, as measured by the FGA, from pre to post intervention (22.8 versus 26.9, p=0.009). 3. Ataxia symptoms significantly decreased from pre-test to post-test (7.3 versus 5.9, p=0.012) 4. There was no significant difference between pre and post-test on FIM.

Author Year Country Study Design Sample Size	Methods	Outcome
<p>Chin et al. (2015) USA Pre-Post N=10</p>	<p>Population: TBI; Mean Age=32.9yr; Gender: Male=4, Female=6; Mean Time Post Injury=6.6yr; Severity: Mild=5, Moderate=4, Severe=1.</p> <p>Intervention: All participants underwent a supervised exercise training program with each session performed on a treadmill (30min 3d/wk for 12wk). The goal was to complete 30 minutes of continuous exercise at a target heart rate (HR) calculated from baseline measures.</p> <p>Outcome Measure: Treadmill Time, Oxygen Consumption (VO2), Work Rate (WR), Heart Rate (HR), Respiratory Exchange Ratio (RER), and Fatigue Severity Scale (FSS).</p>	<ol style="list-style-type: none"> 1. There was a significant increase in treadmill time after training at both peak exercise (16.4 versus 17.8 min; p<0.001) and submaximal exercise (9.3 versus 11.0 min; p<0.001). 2. There was a significant increase in VO2 after training at both peak exercise (37.1 versus 40.2 mL/kg/min; p=0.002) and submaximal exercise (18.9 versus 22.5 mL/kg/min; p<0.001). 3. There was a significant increase in WR after training at both peak exercise (324 versus 383 W; p=0.002) and submaximal exercise (123 versus 160 W; p=0.007). 4. There was no significant difference in HR (p=0.369) or RER (p=0.448) between pre and post exercise. 5. There was a significant reduction (less fatigue) in FSS scores after training (4.1 versus 3.2; p=0.029).
<p>Corral et al. (2014) Spain PCT NInitial=21, NFinal=17</p>	<p>Population: TBI; Mean Age=35yr; Gender: Male=17, Female=0; Time Post Injury>1yr; Mean GCS=6.8.</p> <p>Intervention: Participants were assigned to 1 of 4 groups: 1) Exercise Electro-stimulation group (EEG; n=5; exercise sessions 5d/wk; electrical stimulation 2x20min periods per session), 2) Cycling group (CyG; exercise sessions 3d/wk), 3) Intermittent-hypobaric-hypoxia (IHH) and muscle electro-stimulation group (HEG; n=6; IHH 2h 2d/wk & electro-stimulation 3h 3d/wk) or 4) Control group (CG; n=5; cognitive activities 1h 1d/wk). All groups continued sessions over 12wk.</p> <p>Outcome Measure: Rey Auditory Verbal Learning Test (RAVLT), Trail Making Test A & B (TMT A & B), Stroop Test, Wechsler Adult Intelligence Scale (WAIS III), Barcelona Test, Tower of London Test (ToL), Reduced Paced Auditory Serial Addition Test (PASAT-G), Physical Stress Rest & VO2 Uptake, and Circulating Progenitor Cell (CPC) levels.</p>	<ol style="list-style-type: none"> 1. There were no significant within group differences found for any of the psychological tests (RAVLT, TMT-A & B, Stroop, WAIS III, Barcelona and ToL). 2. The EEG group showed improvement in VO2 uptake and CPC levels. 3. CyG group showed a significant difference in oxygen uptake after 12wk (2.2 versus 2.67 L/min; p=0.043), as well as an improvement on the PASAT-G test. 4. HEG group showed a significant improvement in stress test load (200 versus 218 W; p=0.043); however, there was no significant change in CPC levels. 5. CG showed no significant change on any outcome measure.

Author Year Country Study Design Sample Size	Methods	Outcome
Bhambhani et al. (2005) Canada Case Series N=14	<p>Population: TBI; Mean Age=31.8yr; Gender: Male=10, Female=4; Mean Time Post Injury=17.4mo; Mean GCS=4.6.</p> <p>Intervention: Participants took part in a 12wk circuit training program consisting of 60min sessions designed to enhance muscular strength and aerobic fitness. Five evaluations (T1-T5) were administered during the study period. The circuit training program began at T3.</p> <p>Outcome Measure: Vo2 Levels, Peak Heart Rate, Power Output, Exercise Time, Body Mass Index, and Basal Metabolic Rate.</p>	<ol style="list-style-type: none"> No significant changes were observed in the body mass, basal metabolic rate, or body fat percentage during the study. There were significant increases in peak values of power output, oxygen uptake, and ventilation rate (p values no listed).
Dault & Dugas (2002) Canada PCT N=8	<p>Population: TBI; Mean Age=29.6yr; Gender: Male=6, Female=2; Mean Time Post Injury=44.4mo.</p> <p>Intervention: An individualized 12wk training program (TP; n=5) combining aerobic dance, and slide and step training for 30 min, 2x/wk was compared to traditional muscular training (TMT; n=3) for 60min, 2x/wk for 12wk.</p> <p>Outcome Measure: Test for Sensory Interaction in Balance (CTSIB).</p>	<ol style="list-style-type: none"> Significant pre- and post-training differences were found in the temporal delay for the wrist (p<0.01), knee improvement (p<0.001), and sway area (p<0.05) for the TP group; no significant changes were noted for the TMT group. The temporal delay in the wrist was 83ms in the TP group and 13ms in the TMT group.

Discussion

It appears that the introduction of an aerobic training program can have a positive influence on individuals post ABI. Furthermore, general aerobic programs have been found to improve balance (Dault & Dugas, 2002; Ustinova et al., 2015). It is important to note, that despite improvements in balance, Ustinova and colleagues (2015) did not find improvements in functional independence after the intervention. This suggests that although exercise programs may improve physical fitness, gains in functional status often occur independently of aerobic exercise training. Charrette et al. (2016) conducted a study of intensive exercise programs, consisting of endurance and full body strength training, for adults with chronic severe ABI. Results suggest that intensive combination of interventions improves gait distance and velocity, as well as mobility (Charrette et al., 2016).

Aquatic exercise was found to improve almost all subscales on the Health Promoting Lifestyle Profile, including interpersonal relationships, and also self-esteem— as measured by the Physical Self-Description Questionnaire (Driver et al., 2006). This study encourages participation in group exercise post ABI as it can foster feelings of well-being and self-esteem, which could have a positive impact upon other rehabilitation strategies (Driver et al., 2006).

Bateman et al. (2001) compared cycling training (experimental group) to relaxation training (control group) and found that cycling training was associated with a significant improvement in exercise capacity, however, there was no significant difference between the groups in regards to balance, mobility, and functional independence (Bateman et al., 2001). This suggests that although exercise programs may improve physical fitness, gains in functional status often occur independently of aerobic exercise training (Bateman et al., 2001). Corral et al. (2014) also concluded that cycling training resulted in increased oxygen uptake capacity.

Hassett et al. (2012) examined the benefits of circuit training with encouragement from a physiotherapist and heart rate monitor feedback in individuals with severe TBI. More specifically, the intervention group had their heart rate monitor uncovered and it beeped when they did not reach their target heart rate, whereas the control group had their monitors covered and muted. Results indicate there was no significant difference between the two groups in terms of the amount of time spent in the heart rate target zone. Earlier, Hassett et al. (2009) found individuals assigned to exercise programs showed significant improvement in their cardiorespiratory levels regardless of where they worked out (in a gym or at home) or how often (2.4 sessions per week versus 0.5 sessions per week). Both groups, regardless of treatment condition significantly improved on the shuffle test. However, adherence to the program was higher among those attending a fitness center. When compliance was explored further, those with greater adherence were found to be older, more severely injured and had exercised before the injury (Hassett et al., 2011).

Hoffman et al. (2010) compared individuals who exercised in a community-based program to individuals who did not participate in this program, however, the controls were able to exercise on their own. Although the intervention group was working out more days per week than controls, the total amount of time spent exercising per week was similar between groups, making comparisons challenging. When those who were active (more than 90 minutes of activity per week) were compared to those who were not as active, the authors found that mood was significantly higher in the participants who were exercising for more than 90 minutes each week, regardless of what treatment group they were originally placed in. These individuals also reported a significantly higher quality of life. Furthermore, home-based exercise programs have shown to improve depressive symptoms, stability, motor control test scores, and gait following intervention as well (Bellon et al., 2015; Damiano et al., 2016). It is important to note that one study found that lower stability and dual-tasking scores were associated with poorer mental health outcomes (Damiano et al., 2016).

Two studies have examined the cardiovascular parameters of exercise programs as it relates to motor recovery (Bhambhani et al., 2005; Chin et al., 2015). The two studies examined the effects of supervised exercise training programs, one found that after completing the exercise program there was a significant increase in treadmill time (Chin et al., 2015), while the other found there was a significant increase in oxygen uptake and ventilation rate (Bhambhani et al., 2005). Overall, cardiovascular, and respiratory

parameters were seen to improve in both studies, but it should be noted that Chin et al. (2015) also observed a significant reduction in fatigue.

Conclusions

There is level 1b evidence (from two randomized controlled trials; Hassett et al., 2009; Hassett et al., 2011) that participating in an exercise program at a fitness-center compared to home-based exercise program may lead to greater program adherence but not significantly different motor results in individuals post ABI and those with greater adherence may be more severely injured.

There is level 1b evidence (Hassett et al., 2012) that circuit training with encouragement and heart rate monitor feedback may not significantly improve performance in individuals post ABI.

There is level 2 evidence (from one randomized controlled trial; Hoffman et al., 2010) that community-based exercise may decrease pain and depression in individuals post ABI.

There is level 2 evidence (from one randomized controlled trial; Driver et al., 2006) that aerobic training compared to vocational rehabilitation may be more effective at improving co-ordination, strength, flexibility, and endurance in individuals post ABI.

There is level 1b evidence (from one randomized controlled trial; Bateman et al., 2001) that exercise programs may improve FIM scores, but not balance or mobility compared to relaxation training in individuals post ABI.

There is level 2 evidence (from one prospective controlled trial; Corral et al., 2014) that exercise programs may improve oxygen uptake and CPC levels in individuals post ABI.

There is level 4 evidence (from one pre-post; Charrette et al., 2016) that multimodal exercise programs may improve gait and mobility in individuals post ABI.

There is level 3 evidence (from one case control; Damiano et al., 2016) that a home-based exercise program may improve stability to the level of healthy controls, but may not improve motor control, mobility, or dual-task performance in individuals post ABI.

There is level 2 evidence (from one prospective controlled trial; Dault & Dugas, 2002) that aerobic dance training compared to musculature training may improve sensory interaction and balance post ABI.

There is level 4 evidence (from one pre-post; Ustinova et al., 2015) that a therapeutic exercise program may improve balance and gait, but not FIM scores in individuals post ABI.

There is level 4 evidence (from one case series and one pre-post; Bhambhani et al., 2005; Chin et al., 2015) that aerobic exercise programs may improve cardiovascular parameters following an ABI.



KEY POINTS

- Aerobic exercise programs, whether home-based or in the community, appear to improve motor function, balance, and cardiovascular parameters post ABI
- Further research is needed to determine which components of exercise are the most effective for motor rehabilitation post ABI.

Physiotherapy

Physiotherapy focuses on the biomechanics of the body and helps improve strength, mobility, range of motion, and can also reduce pain. Relevant studies which have examined the impact of physiotherapy for motor rehabilitation following an ABI are presented in Table 13.

TABLE 13 | The use of physiotherapy to improve motor function post ABI.

Author Year Country Study Design Sample Size	Methods	Outcome
<p>Thibaut et al. (2018) United States Case Series N=109</p>	<p>Population: Mean age=40yr; Gender: Male=70, Female=39; Mean time post-injury=38. Intervention: Individuals received between 0 and 3 (low) or between 4 and 6 (high) physiotherapy sessions per week based on their needs. Individuals had all experienced a disorder of consciousness at the time of trauma. Outcome Measures: Modified Asworth Scale (MAS), frequency of muscle contracture.</p>	<ol style="list-style-type: none"> 1. There was a significant difference on the MAS between those who received low vs high physiotherapy (PT), with those having more PT having higher scores (p<0.001). 2. Those in the high PT group also had significantly fewer spastic events (p=0.018). 3. There was a significant negative correlation between the frequency of PT and MAS scores (p<0.001). This relationship was present for chronic-phase patients only (p<0.001). 4. Patients who received lower rates of PT showed higher rates of muscle contracture (p<0.01). There was a significant negative correlation between the frequency of PT and associated MAS scores (p<0.01). When stratified, this correlation was only significant for those in the chronic phase of their injuries (p<0.001).
<p>Mossberg et al. (2002) USA Pre-Post N=40</p>	<p>Population: TBI=35, Stroke=5; Mean Age=33yr; Gender: Male=29, Female=11 Mean Time Post Injury=2.1yr. Intervention: Participants took part in an individualized occupational therapy, physical therapy, speech therapy and neuropsychotherapy program (mean 1hr, 3/wk). Assessments were conducted at baseline and post-intervention. Outcome Measure: Peak Heart Rate, Total Ambulation</p>	<ol style="list-style-type: none"> 1. TAT increased significantly from 10.3±3.1ms at baseline to 13.6±3.5ms at post intervention (p<0.01). 2. Peak Heart Rate (168±20 versus 167±21) and Vo2 levels (23.5±6.6 versus 24.3±6.4, p=0.09) did not change significantly between baseline and post-intervention.

Author Year Country Study Design Sample Size	Methods	Outcome
	Time (TAT), and Vo2 Levels.	
Fan et al. (2020) China RCT PEDro=9 N _{Initial} =87, N _{Final} =81	<p>Population: TBI=87; <i>Intervention Group (Intensive Rehabilitation, n=41):</i> Mean Age=39.25±9.57yr; Gender: Male=22, Female=19; Time Post Injury=7d; Severity: Mean GCS=9.89±2.94.</p> <p><i>Control Group (Standard of care; n=40):</i> Mean Age=38.41±10.39yr; Gender: Male=23, Female=17; Time Post Injury=14d; Severity: Mean GCS=10.01±3.25.</p> <p>Intervention: Participants in the intervention group received early and high-intensity rehabilitation management (7 days after injury, 7d/wk, 4times/d, 1hr session). Rehabilitative treatment training included correct limb positioning and caring of the limbs; passive, assisted, and active movements; strength training; and practice of functional activities. Participants in the control group received the standard of care (14 days after injury, 5d/wk, 2times/d, 1hr session). Outcome measures were assessed at baseline, 1, 3 and 6mo following intervention.</p> <p>Outcome Measures: Glasgow Outcome Scale (GOS), Fugl-Meyer Assessment (FMA), Barthel Index (BI).</p>	<ol style="list-style-type: none"> One month following rehabilitation, no significant differences were observed between groups (p>.05). Three months following rehabilitation: <ul style="list-style-type: none"> FMA score was significantly higher in the group that received early intensive rehabilitation when compared to the control (59.83±11.87 versus 44.56±8.32; p<.05) No significant group differences were observed on the GOS or BI (p>.05). Six months following rehabilitation: <ul style="list-style-type: none"> FMA score and BI score significantly improved with early intensive rehabilitation when compared to the control group (FMA: 73.18±16.55 versus 57.86±10.67, p<.01; BI: 87.17±13.85 versus 60.68±11.98, p<.01).

Discussion

Three studies have investigated the use of physiotherapy and evaluated its effect on motor outcomes following an ABI. In Thibaut et al. (2018), individuals that received higher rates of physiotherapy saw a significant improvement in scores on the Modified Ashworth Scale and had fewer spastic events. Mossberg et al. (2002) also saw a significant improvement in motor outcomes with total ambulation times increasing post-treatment. Fan et al. (2020) found that after receiving early intensive rehabilitation, which involved correct limb positioning and caring of the limbs, passive, assisted, and active movements, strength training, and practice of functional activities, participants with moderate TBI showed significantly greater improvement in motor and neurologic function than those who received standard care alone.

Conclusions

There is level 4 evidence (from one case series; Thibaut et al., 2018; and one pre-pos study; Mossberg et al., 2002) that physiotherapy may improve motor outcomes such as ambulation, spasticity and gross motor function following an ABI.

There is level 1b evidence (from one randomized controlled trial; Fan et al., 2020) that early intensive rehabilitation management might be more beneficial for neurologic function and activities of daily living in individuals with moderate TBI.



KEY POINTS

- **Physiotherapy and early intensive rehabilitation management likely improves ambulation and motor function following an ABI.**

Spasticity Interventions

Spasticity is a common symptom encountered post ABI and is an element of UMNS. Spasticity has been formally defined as “a motor disorder characterized by a velocity-dependent increase in tonic stretch reflexes with exaggerated tendon reflexes, resulting from excitability of the stretch reflex” (Lance, 1980). Common features of spasticity include increased muscle tone, exaggerated tendon jerks, and clonus.

Management of spasticity is not unique to brain injury survivors, since it is often associated with other conditions affecting the central nervous system such as spinal cord injury and multiple sclerosis. Spasticity may require intervention when it interferes with functional abilities such as mobility, positioning, hygiene, or when it is the cause of deformity or pain. Factors that must be taken into consideration when proposing treatment of spasticity include chronicity of the problem, the severity, the pattern of distribution (focal versus diffuse), the locus of injury, as well as comorbidities (Gormley et al., 1997). Some studies have found that spasticity of cerebral origin versus spinal cord injury respond differently to the same medications (Katz & Campagnolo, 1993). Typically, the clinical approach to spasticity is to first employ treatments that tend to be less interventional and costly, however, multiple strategies may need to be administered concurrently. Although surgery is a viable intervention for the treatment of spasticity, no studies meeting our inclusion criteria have examined surgery as an intervention for the management of spasticity following an ABI (Duquette & Adkinson, 2018).

Botulinum Toxin Injections

Botulinum toxin type A (BTX-A) acts at the pre-synaptic terminal to block acetylcholine release into the neuromuscular junction. When selectively injected into a specific muscle BTX-A is thought to cause local muscle paralysis, thereby alleviating hypertonia caused by excessive neural activity (Jankovic & Brin, 1991). It has been suggested that BTX-A may be useful in the treatment of localized spasticity if oral interventions such as benzodiazepines, baclofen, dantrolene sodium, or tizanidine cause significant adverse effects (Gracies, Nance, et al., 1997). A limited number of RCTs exist evaluating botulinum toxin for spasticity in individuals with an ABI (Table 14).

TABLE 14 | Botulinum Toxin for the Treatment of Spasticity Post ABI

Author Year Country Study Design Sample Size	Methods	Outcome
<p>Mayer et al. (2008) USA RCT PEDro=6 N=31</p>	<p>Population: TBI=21, Stroke=8, Hypoxic encephalopathy=2; <i>Motor Point Group:</i> Mean Age=37.9yr; Mean Time Post Injury=256.7 d. <i>Distributed Group:</i> Mean Age=34.7yr; Mean Time Post Injury=481.9yr. Intervention: Patients with severe elbow flexor hypertonia received one of two interventions: the motor point injection technique (1 site biceps and 1 site brachioradialis), or the distributed quadrants technique (4 sites rectangularly configured – 2 biceps and 2 brachioradialis). Following two baseline measures, each elbow was randomized to receive injections of Botox. In total 90 units were given to patients in each group. However, the sites and injection techniques varied between the groups. Mean follow up was 23.5±4.4d. Outcome Measure: The Ashworth Scale, Modified Tardieu Scale.</p>	<ol style="list-style-type: none"> 1. The median decrease in Ashworth Scores after intervention was 1 point in both groups (p=0.53) and the Tardieu catch angle post intervention did not differ significantly between groups (p=0.31). 2. Both groups showed significant improvement from baseline on all outcomes measured (all p<0.01); however, there were no between-group differences at 3wk. For both groups, a clinicophysilogic effect was observed at 3wk post-intervention.
<p>Verplancke et al. (2005) UK RCT PEDro=4 N=35</p>	<p>Population: TBI=20, Neurosurgery=11, Anoxia=4; Gender: Male=25, Female=10. <i>Group 1 (n=11):</i> Median Age=40yr; Mean Time Post Injury=9.3d, Mean Glasgow Coma Scale (GCS) score 4.3. <i>Group 2 (n=12):</i> Median Age=33.5yr; Mean Time Post Injury=13.25 days; Mean GCS score=4.7. <i>Group 3 (n=12):</i> Median Age=41.5yr; Mean Time Post Injury=10.6d; Mean GCS score=5.2. Intervention: Participants entered one of three groups: group 1 received a physical intervention (controls), group 2 received casting plus injections of saline (4 ml), and group 3 received casting with botulinum toxin (100 units per leg) into the gastrocnemius and soleus muscles. Patients were re-cast if a 10° change in dorsiflexion occurred. Outcome Measure: Calf contracture, Modified Ashworth Scale (MAS), Passive Range of Motion.</p>	<ol style="list-style-type: none"> 1. Eighty-eight percent of patients developed spasticity within 14 days of injury. 2. Mean change in angle of passive ankle dorsiflexion was 4.59° in controls, 11.69° in group 2 and 13.59° in group 3. 3. There were significant improvements in MAS scores in treated groups (group 2, p<0.03; group 3, p=0.04) but not controls (p>0.05).

Author Year Country Study Design Sample Size	Methods	Outcome
<p>Intiso et al. (2014) Italy Pre-Post N=22</p>	<p>Population: ABI=16, Cerebral Palsy=6; Mean Age=38.1yr; Gender: Male=12, Female=10; <i>Brain Injury:</i> Mean Time Post Injury=3.8yr. Intervention: Patients with severe spasticity of the upper and lower limbs received injections of onabotulinum toxin A (BoNT-A; up to 840 IU). Outcome Measure: Modified Ashworth Scale (MAS), Glasgow Outcome Scale (GOS), Frenchay Arm Test (FAT), Barthel Index (BI), Visual Analog Scale, Visual Analogue Scale–Pain (VAS).</p>	<ol style="list-style-type: none"> Seventeen patients had spastic hemiparesis and 5 had paraparesis. A significant reduction in spasticity was seen at 4 and 16wk post intervention, shown by a decrease in mean MAS scores in the elbow, wrist, finger, and hand (all $p<0.05$) and ankle ($p<0.03$). No significant improvements were seen on the GOS, BI, or FAT at 4 or 16 wk. A significant reduction in pain was seen from baseline (7.6 ± 1.1) to 4 (3.5 ± 0.7) and 16 wk (3.6 ± 0.5) post intervention ($p<0.001$).
<p>Clemenzi et al. (2012) Italy Pre-Post N=21</p>	<p>Population: TBI=11, ABI=10; Mean Age=42.2yr; Gender: Male=16, Female=5; Median Time Post Injury=5yr; Severity: Severe. Intervention: Patients received repeated injections of Botulinum Toxin Type A (maximum dose 600 U diluted in 50 ml⁻¹) followed by rehabilitation program that consisted of hand and/or foot adhesive taping maintained for 7d and checked daily. Outcome Measure: Barthel Index (BI), Modified Ashworth Score (MAS), Visual Analogue Scale- pain (VAS).</p>	<ol style="list-style-type: none"> Spasticity was in the lower limb in 33.3% of patients, upper limb in 9.5%, and both in 57.1%. MAS lowered at the follow up, and improvement in spasticity was seen at the second and last injection (T3) time points compared to baseline ($p<0.0001$). BI significantly improved at follow up (T3) in relation to initial scores ($p=0.0001$). VAS score improved at the end of the second injection, a reduction in score was noted after each injection. Greater improvement on BI was correlated to a shorter period between ABI onset and first injection ($p<0.0001$), the same effect was not discovered for MAS or VAS.
<p>Yablon et al. (1996) USA Case Series N=21</p>	<p>Population: TBI; Mean Age=28.2yr; Gender: Male=12, Female=9; Mean Time Post Injury: Acute Group=142.7d, Chronic Group=89.5mo. Intervention: Participants received Botulinum Toxin A injections (20-40 units per muscle) into the upper extremity. Targeted muscles included: the flexor carpi radialis, flexor carpi ulnaris, flexor digitorum profundus, and flexor digitorum superficialis. Some patients also received injections into the biceps and brachialis due to coexisting spasticity in the elbow flexors. After injection, patients received therapeutic modalities as needed. Patients were grouped based on time between injury and injection: acute (<12mo; $n=9$) or chronic (≥ 12mo; $n=12$). Outcome Measure: Modified Ashworth Scale (MAS), passive ROM at the wrist.</p>	<ol style="list-style-type: none"> The acute group showed significant improvements in ROM (wrist extension improved by a mean of $42.9\pm 24.7^\circ$, $p=0.001$) and spasticity severity (mean MAS improvement 1.5 ± 0.5 points, $p=0.01$). All patients in the acute group showed an improvement in spasticity and no patient worsened or remained unchanged. The chronic group showed significant improvements in ROM (wrist extension improved by a mean of $36.2\pm 21.7^\circ$, $p<0.001$) and spasticity severity (mean MAS improvement 1.47 ± 0.9 points, $p=0.002$).

Discussion

Five studies examining the effects of BTX-A on spasticity following ABI were identified. Intiso et al. (2014) showed a reduction in spasticity for the upper extremity (elbow, wrist, and hand), as well as ankle joints at one and four months post intervention. Although pain was also significantly reduced, no significant improvements in function were shown— as measured by the Glasgow Outcome Scale and the Frenchay Arm Test (Intiso et al., 2014). These findings were similar to those found by Yablon et al. (1996) who reported that BTX-A injections into the upper extremities improved range of motion and spasticity in 21 patients with ABI. These improvements were shown for patients who received the injections within one year of injury and also for those who received the injection more than one year post injury (Yablon et al., 1996). The time between injury and injection was also studied by Clemenzi et al. (2012). The results were similar to the previous study for pain and spasticity, however, the time between onset and injection did have an effect on functional outcomes. Patients with a shorter period of time between their injury and first injection had greater improvements on the Barthel Index (Clemenzi et al., 2012).

In terms of the administration of BTX-A, Mayer et al. (2008) found that a single motor point injection and multisite distributed injection resulted in similar outcomes, with both groups showing a clinical effect at three weeks post intervention.

Conclusions

There is level 4 evidence (from one pre-post test; Intiso et al., 2014) that botulinum toxin type A injections may be effective in the management of localized spasticity following ABI.

There is level 1b evidence (from one randomized controlled trial; Mayer et al., 2008) that receiving botulinum toxin type A through a single motor point or multisite distributed injections are similar at reducing spasticity in individuals with an ABI.

There is level 1b evidence (from one randomized controlled trial; Verplancke et al., 2005) that botulinum toxin injections in combination with casting may be as effective as casting alone at reducing leg spasticity in patients post ABI.

There is level 4 evidence (from one pre-post test; Clemenzi et al., 2012; and one case series; Yablon et al., 1996) that botulinum toxin A injections in conjunction with conventional therapies may improve spasticity and passive ROM in patients with TBI.



KEY POINTS

- Botulinum toxin type A injections are effective in the management of localized spasticity following an ABI.
- Botulinum toxin injections in combination with casting may be as effective as casting alone at reducing leg spasticity in patients post ABI.
- Botulinum toxin type A injections, whether through a single point or multisite, likely reduce localized spasticity following ABI.

Nerve Blocking Agents

Local nerve blocks are a potential management solution in circumstances where there is muscle spasticity affecting only a few muscle groups in a focal pattern. Essentially, a nerve block involves the application of a chemical agent to impair nerve functioning. The effect of the chemical agent may be temporary or permanent (Katz et al., 2000). Temporary acting compounds include local anesthetic agents that block sodium ion channels, typically lasting only a few hours. Local anesthetic agents are used for diagnostic procedures or for assistance with activities such as casting (Gracies, Elovic, et al., 1997). Agents used for permanent nerve blocks to treat spasticity last between 2 and 36 months and include ethyl alcohol (>10%) and phenol (>3%). Complications of this type of block have included chronic dysesthesia, pain and permanent peripheral nerve palsies (Gracies, Elovic, et al., 1997). Studies of nerve blocking agents to improve spasticity in individuals with an ABI are limited (Table 15).

TABLE 15 | Percutaneous Phenol Block for the Treatment of Spasticity Post ABI

Author Year Country Study Design Sample Size	Methods	Outcome
Keenan et al. (1990) USA Case Series N=17	<p>Population: TBI; Mean Age=25yr; Gender: Male=12, Female=5; Mean Time Post Injury=6mo.</p> <p>Intervention: Participants received a phenol block (3ml of 5% phenol solution in sterile saline) followed by a daily program of active/passive range of motion therapy. Assessments conducted pre-post block, 24hr after, then at weekly intervals while patients were hospitalized for rehabilitation. Post discharge follow-up occurred for a minimum of 2yr.</p> <p>Outcome Measure: Muscle tone/control, Range of Motion.</p>	<ol style="list-style-type: none"> 1. Ninety-three percent of extremities showed a short-term decrease in motor tone and improved resting position of the elbow. 2. Maximum improvements occurred 4wk post block. 3. Resting position improved from 120° to 69°, active arc increased from 46° to 60°, and passive arc from 65° to 118°. 4. At follow-up (mean 27mo post injection), 9 extremities that had relief of spasticity, had recurrence of flexor tone and loss of motion in the elbow.

Author Year Country Study Design Sample Size	Methods	Outcome
Garland et al. (1984) USA Case Series N=11	<p>Population: TBI=11; Mean Age=24yr; Gender: Male=8, Female=3; Mean Time Post Injury=5.8mo.</p> <p>Intervention: Participants received percutaneous phenol injections (1-2ml of 3 or 5% phenol solution) at motor points of spastic wrist and finger flexors identified using a nerve stimulator. Injected muscles included: the flexor carpi radialis, flexor carpi ulnaris, flexor digitorum sublimus, flexor digitorum profundus, and flexor pollicis longus.</p> <p>Outcome Measure: Resting Angle of Wrist, Passive/active Extension of Wrist.</p>	<ol style="list-style-type: none"> 1. Mean resting position of the wrist prior to injection was 53°. Nine patients increased resting extension by a mean of 34° and 2 patients lost a mean of 15° of extension. 2. Overall, there was a mean increase in resting wrist angle following motor point injections of 25°. 3. Active wrist extension improved an average of 30°. Mean increase in passive wrist extension with finger flexed of 5°.

Discussion

We identified two studies which evaluated the efficacy of nerve blocks as a treatment for spasticity. Keenan et al. (1990) evaluated the effect of percutaneous phenol block of the musculocutaneous nerve to decrease elbow flexor spasticity. The results indicated that there was improved range of motion of the elbow lasting a mean of five months. In the second study, 11 closed head injury patients with spastic paralysis of the upper extremity were treated with percutaneous phenol injections into the spastic wrist and finger flexors (Garland et al., 1984). The authors reported that relaxation of muscle tone persisted for up to two months following the injections. Furthermore, there was a mean increase in resting wrist angle, active wrist extension, and passive wrist extension with fingers flexed of 25, 30, and 5°, respectively (Garland et al., 1984). Evidently, these studies found that percutaneous phenol blocks are effective in temporarily controlling spasticity in patients post TBI, however, due to the retrospective nature of the studies and lack of controls there is insufficient evidence to make definitive conclusions on the efficacy of phenol injections.

Conclusions

There is level 4 evidence (from two case series; Keenan et al., 1990; Garland et al., 1984) that phenol nerve blocks may reduce contractures and spasticity at the elbow, wrist, and finger flexors for up to five months post injection in individuals post ABI.



KEY POINTS

- Phenol blocks of the musculocutaneous nerve may help decrease spasticity and improve range of motion temporarily up to five months post injection in individuals with ABI.

Electrical Stimulation

Electrical stimulation uses an electrical current to elicit a muscle contraction either directly by stimulating the skeletal muscle (Gregory & Bickel, 2005), or indirectly by stimulating the nerve supplying that muscle. Electrical stimulation has seen some applications with regards to assisting paraplegic patients with standing and walking (Katz et al., 2000). Reports from spinal cord injury populations suggest that electrical stimulation is associated with significant reductions in spasticity for up to 24 hours post-stimulation (Halstead et al., 1993) (Table 16).

TABLE 16 | Electrical Stimulation for the Treatment of Spasticity Post ABI

Author Year Country Study Design Sample Size	Methods	Outcome
<p>Leung et al. (2014) Australia RCT PEDro=8 N_{Initial}=35, N_{Final}=32</p>	<p>Population: TBI; <i>Experimental Group (EG; n=17)</i>: Mean Age=38yr; Gender: Male=14, Female=3; Mean Time Post Injury=140d; Mean GCS=5. <i>Control Group (CG; n=18)</i>: Mean Age=38yr; Gender: Male=15, Female=3; Mean Time Post Injury=83d; Mean GCS=5. Intervention: Participants were randomly allocated to either the EG or CG group. The EG group underwent a treatment of tilt table standing and electrical stimulation (30 min 5d/wk) and splinting (12hr 5d/wk) for a total of 6 wk. For the next 4wk EG group participants underwent tilt table standing alone (30 min 3d/wk). The CG group underwent tilt table standing (30min 3d/wk) for the full 10 wk. Measures were taken at baseline, 6wk and 10wk. Outcome Measure: Passive ankle dorsiflexion, Functional Independence Measure (FIM).</p>	<ol style="list-style-type: none"> The CG group had a greater range of motion for passive ankle dorsiflexion than the EG group at 6 wk (3 degrees) and 10 wk (-1 degree). The EG group had a greater mean reduction in spasticity (1 point) at 6 wk; however, the effect disappeared at 10 wk. There was no between group differences in walking speed. There were no differences between groups for tolerance to treatment, perceived treatment benefit, perceived treatment worth, and willingness to continue with treatment.
<p>Seib et al. (1994) USA Pre-Post N=10</p>	<p>Population: TBI=5, Spinal Cord Injury=5; Mean Age=38yr; Gender: Male=6, Female=4; Mean Time Post Injury=6.3yr. Intervention: After baseline assessments, 20 min of Surface Electrical Stimulation to the ipsilateral (the more spastic side) tibialis anterior. Parameters: 2sec rise time, 15 sec on, instant fall, 20sec off. Rate of stimulation was 30 pulses/sec. Intensity varied on participant tolerance. Assessments occurred at baseline, immediately post intervention, and 24hr after the intervention. Outcome Measure: Path length, Spasticity Measurement System.</p>	<p>Ipsilateral Effect:</p> <ol style="list-style-type: none"> There was a significant reduction in spasticity immediately following stimulation for all participants (p<0.05). However, the change in path lengths pre to post stimulation was not significantly different in the TBI group alone (median length 82nm/rad before versus 73nm/rad after). Twenty-four hours after stimulation, ipsilateral path length (spasticity) reduced significantly in 8 of 9 participants (p<0.01). <p>Contralateral Effect:</p> <ol style="list-style-type: none"> Six of 9 participants showed increased contralateral path lengths immediately post intervention. TBI median path length increase was from 14nm/rad to 34nm/rod.

Author Year Country Study Design Sample Size	Methods	Outcome
		5. Twenty-four hours post stimulation, 4 patients had decreased spasticity, 3 had an increase and 1 patient had no change.

Discussion

One study by Seib et al. (1994) was identified which examined the effects of electrical stimulation applied to the lower extremity in participants with either a TBI or spinal cord injury. Electrical stimulation significantly decreased spasticity in the stimulated extremity, whereas the tone in the non-stimulated extremity did not change. Furthermore, the effect of one stimulation session was noted to last up to 24 hours post intervention.

Conclusions

There is level 1b evidence (from one randomized controlled trial; Leung et al., 2014) that electrical stimulation in combination with tilt table standing and splinting may decrease spasticity at 6 weeks post intervention compared to tilt table standing alone in patients with an ABI.

There is level 4 evidence (from one pre-post test; Seib et al., 1994) that electrical stimulation may be effective for decreasing lower extremity spasticity for six or more hours, lasting up to 24 hours, in individuals post ABI.



KEY POINTS

- Electrical stimulation may acutely (24 hours) decrease spasticity in patients post ABI.
- Electrical stimulation in combination with tilt table standing and splinting may acutely improve spasticity (6 weeks) in patients post ABI.

Oral Antispasticity Drugs

Oral agents are often used to manage spasticity, particularly when a systemic agent to treat upper and lower extremity spasticity is required (Gracies, Nance, et al., 1997). Although antispasticity agents may be used for other medical conditions such as spinal cord injury or multiple sclerosis (Gracies, Nance, et al., 1997), the effectiveness of these agents should not be presumed to be similar for brain injury survivors. Multiple medications have been evaluated to treat spasticity of both cerebral and spinal cord origin. The more common medications include GABA agonists, that affect ion flux such as baclofen, benzodiazepines, dantrolene sodium, as well as agents that affect alpha-2 adrenergic receptors such as tizanidine and clonidine. The use of any of these drugs must be weighed against potential side effects,

such as sedation, which are complicated by the cognitive and behavioural changes associated with brain injury (Table 17).

TABLE 17 | Oral Antispasticity Agents for the Treatment of Spasticity Post ABI

Author Year Country Study Design Sample Size	Methods	Outcome
Meythaler et al. (2004) USA Case Series N=35	<p>Population: TBI=22, ABI=6, Stroke=7; Mean Age=31yr; Gender: Male=22, Female=13.</p> <p>Intervention: Oral baclofen regimen beginning at 5 mg 3x/day increased per protocol to 80mg/day. Follow-up occurred between 1 and 3mo after initiation of oral baclofen.</p> <p>Outcome Measure: Ashworth Rigidity Scale (ARS), Spasm Frequency Scale (SFS), Deep Tendon Reflexes (DTR).</p>	<ol style="list-style-type: none"> Mean dose was 57±26mg/day for all patients and 55 ± 28mg/day for patients with TBI. After treatment, extremity ARS (3.5±1.1 to 3.2±1.2, p=0.0003) and DTR scores (2.5±0.9 to 2.2±1.2, p=0.0274) decreased significantly. No significant changes in lower extremity spasm scores were observed. Patients with TBI saw a significant decrease in scores on the ARS (p=0.0044) and DTR (p=0.0003) but not on the SFS (p>0.05). Upper extremities showed no significant changes for tone, spasm frequency, or reflexes (p>0.05).

Discussion

Meythaler et al. (2004) completed a retrospective study evaluating the use of oral baclofen to manage spasticity in a mixed brain injury and stroke population. Pre and post testing revealed that oral baclofen improved spasticity in the lower extremity assessed using the Ashworth Rigidity Scale and Spasm Frequency Scale. However, no changes for tone, spasm frequency, or reflexes were found for the upper extremity (Meythaler et al., 2004). The authors suggest that the lack of effect may be due in part to receptor specificity issues. Of note, a common adverse effect of the oral baclofen was the onset of considerable sleepiness in 17% of patients (Meythaler et al., 2004).

Of note, Meythaler et al. (2001) completed a randomized, double blinded placebo controlled cross over trial examining tizanidine for the management of spasticity. This study evaluated both stroke (53%) and TBI (47%) survivors. For both lower and upper extremity, there was a significant decrease in the Ashworth scores on the affected side with the active drug compared to placebo. However, significant differences between interventions were not found for upper and lower extremity spasm and reflex scores. Overall, the authors felt that tizanidine was effective in decreasing the spastic hypertonia associated with ABI; however, a common side effect was increased somnolence (41%) (Meythaler et al., 2001). Despite the study showing effectiveness, no level of evidence will be assigned for this drug due to more than 50% of the population being stroke.

Conclusions

There is level 4 evidence (from one case series; Meythaler et al., 2004) that oral baclofen may improve lower extremity spasticity, but not upper extremity spasticity, in individuals post ABI.



KEY POINTS

- Oral baclofen may reduce lower extremity, but not upper extremity, spasticity in individuals with an ABI.

Intrathecal Baclofen

A limitation of oral baclofen is the inability to achieve sufficiently high concentrations in the cerebrospinal fluid (CSF) in order to modify spasticity without first causing significant sedation (Gracies, Nance, et al., 1997). Intrathecal baclofen refers to direct administration of baclofen into the intrathecal space and CSF at the lumbar level. For therapeutic treatment, a subcutaneous pump is required to provide continuous administration of the medication into the intrathecal space. This treatment procedure, however, is invasive and associated with complications including infection, pump failure, and tube complications such as kinking or disconnection (Gracies, Nance, et al., 1997) (Table 18).

TABLE 18 | Intrathecal Baclofen for the Treatment of Spasticity Post ABI

Author Year Country Study Design Sample Size	Methods	Outcome
Meythaler et al. (1996) USA RCT PEDro=7 N=11	<p>Population: TBI=10, Anoxia=1; Mean Age=25yr; Gender: Male=9, Female=2.</p> <p>Intervention: Patients with chronic spastic hypertonia received either a bolus injection of intrathecal baclofen (50µg) or placebo (normal saline). Crossover occurred a minimum of 48hr later. Assessment at 1, 2, 4, and 6hr post injection.</p> <p>Outcome Measure: Ashworth Scale (AS), Spasm Score, Deep Tendon Reflexes.</p>	<ol style="list-style-type: none"> 1. For the lower extremity, after baclofen injection, AS scores decreased by a mean of 2 points (p=0.0033), spasm scores decreased by a mean of 2.1 points (p=0.0032), and reflex scores by 2.3 points (p=0.0032) at 4h. 2. For the upper extremity, after baclofen injection, AS scores decreased by a mean of 1.4points (p=0.0033), spasm scores by a mean of 1.2points (p=0.0070), and reflex scores by 1.0points (p=0.0111) at 4h. 3. No significant within-group differences were shown for placebo. Between group differences were significant for all measures for both lower and upper extremity (p≤0.0272).

Author Year Country Study Design Sample Size	Methods	Outcome
<p>Wang et al. (2016) Singapore Case Series N_{Initial}=6, N_{Final}=5</p>	<p>Population: TBI=5, Encephalopathy=1; Mean Age=31.6yr; Gender: Male=3, Female=2; Mean Time Post Injury=39.4mo. Intervention: A retrospective review of patients that were recruited to undergo surgical implantation of an intrathecal baclofen (ITB) pump. After implantation patients received daily physical therapy. Upon discharge patients continued to receive regular outpatient rehabilitation therapies for 3mo, and ITB pump refills and monitoring by the neurosurgical team for 3-4 mo. Outpatient follow-up was 3-6mo. Outcome Measure: Modified Ashworth Scale (MAS).</p>	<ol style="list-style-type: none"> The mean reduction in MAS was 1.2 (SD 1.1; p<0.05) at 3mo and 1.0 (SD 1.2; p=0.06) at the last follow-up. All patients but 1 (no change) had significant reductions in spasticity.
<p>Chow et al. (2015) Canada Pre-Post N=19</p>	<p>Population: TBI=11, Stroke=8; Mean Age=34.2yr; Gender: Male=9, Female=10; Mean Time Post Injury=48.7mo. Intervention: All patients underwent a 50-µg intrathecal baclofen (ITB) bolus injection via lumbar puncture. Patients were evaluated at baseline, 2hr, 4hr, and 6hr post injection. Outcome Measure: Gait speed, stride length, cadence, stance duration, ankle range of motion (ROM)-stance & swing, peak medial gastrocnemius (MG) lengthening velocity, average Ashworth Score, Plantar Flexors Ashworth Score, Electromyography-lengthening Velocity (EMG-LV), Coactivation Duration (CoD), Coactivation Index (CI).</p>	<ol style="list-style-type: none"> There was no significant difference in gait speed, stride length, cadence, or stance duration across evaluation points. Ankle ROM in the more-affected leg during stance phase was significantly increased from baseline to 6hr (p=0.009); however, was not significantly different during swing phase. Peak MG lengthening velocity significantly increased from baseline to 4hr in the less-affected leg (p=0.005) and to 6hr in both legs (p<0.01). Average Ashworth Score and plantar flexors Ashworth scores were significantly different across all time posts in the more-affected leg only (p<0.001). Compared with baseline, both frequency (p=0.02) and average gain (p=0.007) of EMG-LV were significantly lower at 2 hr post but did not reach the significance at 4hr and 6hr post (p<0.040). Slope parameters of EMG-LV in the less-affected leg did not change over time (p>0.129). CoD significantly decreased over time in the more affected leg during all phases of gait (p<0.013); and CoI did not significantly change over time in either leg (p>0.107).
<p>Margetis et al. (2014) Greece Pre-Post N=8</p>	<p>Population: TBI=6, Hydrocephalus=1, Cardiac Arrest=1; Mean Age=31.5yr; Gender: Male=8, Female=0; Mean Time Post Injury=37.25mo. Intervention: Patients who were resistant to oral spasticity treatments received an implanted intrathecal baclofen pump. Mean follow-up period was 38.4mo. Outcome Measure: Modified Ashworth Scale.</p>	<ol style="list-style-type: none"> All patients showed improvement in their spasticity scores; mean Modified Ashworth Scale scores were 3.375 pre- and 1.125 post-intervention.

Author Year Country Study Design Sample Size	Methods	Outcome
<p>Posteraro et al. (2013) Italy Pre-Post N=12</p>	<p>Population: TBI=8, Hemorrhage=2, Anoxia=2; Mean Age=36yr; Gender: Male=9, Female=3; Time Post Injury Range=31-150d.</p> <p>Intervention: Patients not experiencing reductions in spasticity following initial interventions with oral baclofen received intrathecal baclofen (ITB). The initial dosage was 50 or 100mcg depending on the severity of the impairment and was increased by 10% every 3d until the maximum dosage of 800 mcg was achieved. Assessments occurred before the implant, and at 3mo and 12mo follow-ups.</p> <p>Outcome Measure: Modified Ashworth Scale (MAS), Spasm Frequency Scale (SFS), Disability Rating Scale (DRS), Level of Cognitive Functioning (LCF).</p>	<ol style="list-style-type: none"> 1. Mean ITB dose for participants was 380mcg. 2. Six patients received ITB within 3mo of injury (early); 6 patients received ITB between 3 and 6mo post injury (late). 3. At 3mo, both spasticity and spasms significantly decreased compared to the baseline, based on MAS and SFS scores ($p<0.001$ and $p<0.002$, respectively). 4. At 3mo, improvements in DRS and LCF were seen ($p<0.001$ and $p=0.002$, respectively). 5. At 12mo (n=5) all patients demonstrated further improvements in spasticity and spasms, but this was non-significant compared to results at 3 mo. 6. There were no differences in global outcomes (DRS and LCF) between patients in early ITB initiation group and those in late ITB initiation group.
<p>Hoarau et al. (2012a) France Post-Test N=43</p>	<p>Population: TBI; Mean Age=23.3yr; Gender: Male=33, Female=10; Mean GCS score=4.6.</p> <p>Intervention: After initial injury, participants who were started on Intrathecal Baclofen Therapy (IBT) to treat dysautonomia and hypertonia and were included for evaluation of long-term outcomes (mean 10 ± 0.6yr post implantation).</p> <p>Outcome Measure: Coma Recovery Scale-Revised (CRS-R), Modified Ashworth Scale (MAS), Barthel Index (BI).</p>	<ol style="list-style-type: none"> 1. At follow-up, 9 participants had died, 13 were severely disabled or in an unresponsive wakefulness syndrome and 21 had a good recovery of consciousness. 2. Mean CRS-R score was 18.9 (Range 1-23), mean BI score was 50.1 (Range 0-100), 34.9% were living at home, and mean MAS for upper limb was 1.6 (Range 0-4). 3. Most of the participants who had a positive recovery received IBT later than the other participants. 4. Complications occurred in 62.8% of patients; the most common being operative site infections (20.9%) and overdoses with profound flaccidity, sedation, and vomiting (16.3%).
<p>Horn et al. (2010) USA Pre-Post N=28</p>	<p>Population: TBI=12, Hypoxic Encephalopathy=3, Stroke=13; Mean Age=35yr; Gender: Male=12, Female=16; Mean Time Post Injury=45mo.</p> <p>Intervention: Participants received a 50µg bolus of baclofen injected into the lumbar intrathecal space.</p> <p>Outcome Measure: Ashworth Scale, Video-based Motion Analysis Program.</p>	<ol style="list-style-type: none"> 1. The range of motion (ROM) increased in the ankle on both the more involved side (13 ± 6 versus 15 ± 7, $p=0.008$) and the less involved side (22 ± 8 versus 24 ± 8, $p=0.031$) from baseline to post-injection. 2. ROM improvement occurred most often at 4 and 6hr after injection ($p<0.05$). 3. There was a significant correlation between the magnitude of change in ROM at the time of peak response and the magnitude of gait speed change ($r=0.1$, $p<0.001$). 4. Significant reductions in Ashworth scores compared to baseline (2.0 ± 0.5) at 2hr (1.6 ± 0.4), 4 hr (1.4 ± 0.4) and 6 hr (1.3 ± 0.3) post-injection (all $p<0.001$).

MOTOR AND SENSORY IMPAIRMENT REHABILITATION POST ACQUIRED BRAIN INJURY

Author Year Country Study Design Sample Size	Methods	Outcome
<p>Stokic et al. (2005) USA Case Series N=30</p>	<p>Population: TBI=17, Anoxic=4, Stroke=9; Mean Age=31yr; Gender: Male=17, Female=13; Mean Time Post Injury=3yr. Intervention: Participants received a single 50µg intrathecal baclofen bolus injection via a lumbar puncture. Outcome Measure: Ashworth Scale, H-Reflex from Soleus Muscle, F waves from Abductor Hallucis in Supine Position.</p>	<ol style="list-style-type: none"> Ashworth score on the more involved side significantly decreased between baseline (2.4±0.7) and 4 (1.5±0.6) and 6 hr (1.4±0.6) post-injection (p<0.001). Maximal individual change in Ashworth scores ranged from 0 to 2.6 points (mean 1.0±0.7). H/M ratio significantly decreased bilaterally (p<0.001). F-wave persistence significantly decreased on the more involved side (p<0.05) with no change in F/M ratio.
<p>Francisco et al. (2005) USA Case Series N=14</p>	<p>Population: Anoxic Encephalopathy=6, TBI=5, Stroke=3; Mean Age=35.9yr; Gender: Male=6, Female=8. Intervention: Patients were surgically fitted with an infusion pump for continuous intrathecal baclofen delivery. This took place a mean of 5.62mo (range 2-12mo) post injury. Follow up occurred at a mean of 13.9mo post pump implantation. Outcome Measure: Modified Ashworth Scale (MAS), Disability Rating Scale (DRS).</p>	<ol style="list-style-type: none"> Participants received a mean daily intrathecal baclofen dose of 591.5µg (93-2000.2µg). From baseline to follow-up, the mean decrease in MAS scores for upper extremities was 1±1.4 (p<0.020) and lower extremities was 2.1±1.4 (p<0.001). The changes in DRS scores were not significant.
<p>Horn et al. (2005) USA Pre-Post N=28</p>	<p>Population: TBI=12, Stroke=13, Hypoxic Encephalopathy=3; Mean Age=35yr; Gender: Male=12, Female=16; Mean Time Post Injury=45mo. Intervention: Participants received a single 50µg intrathecal baclofen bolus injection via lumbar puncture. Outcome Measure: Walking Performance, Ashworth scores.</p>	<ol style="list-style-type: none"> Mean change in hip and knee range of motion (ROM) during gait was less than ±2° after injection. ROM in ankles increased from baseline to post-injection on both the more involved (13° versus 15°, p<0.010) and less involved side (22° versus 24°, p<0.050). For all joints (n=168), ROM significantly improved in 42%, significantly worsened in 34%, and did not change in 24%. Significant reductions in Ashworth scores compared to baseline (2.0±0.5) at 2hr (1.6±0.4), 4hr (1.4±0.4) and 6hr (1.3±0.3) post-injection (all p<0.001).
<p>Dario et al. (2002) Italy Pre-Post N=14</p>	<p>Population: TBI=6, Anoxic ABI=8; Mean Age=38.8yr; Gender: Male=10, Female=4; Mean Time Post Injury=36.7mo. Intervention: Patients received continuous intrathecal baclofen infusions through the implantation of a subcutaneous pump. Mean length of spasticity was 36.7mo post injury. Outcome Measure: Ashworth Scale (AS), Spasm Frequency Scale (SFS).</p>	<ol style="list-style-type: none"> Between pre-operative through the last follow up, there was a significant decrease in AS scores in both lower (4.3±0.5 versus 2.7±0.7) and upper (4.1±0.8 versus 2.3±0.9) extremities (both p<0.05). Significant reduction in SFS scores was found between preoperative and postoperative values (2.5±0.5 versus 0.4±0.6, p<0.001). Mean daily dose of baclofen was 305µg (range 90-510µg).

MOTOR AND SENSORY IMPAIRMENT REHABILITATION POST ACQUIRED BRAIN INJURY

Author Year Country Study Design Sample Size	Methods	Outcome
<p>Francois (2001) France Case Series N=4</p>	<p>Population: TBI; Mean Age=19.5yr; Gender: Male=1, Female=2, Unknown=1; Mean GCS=3.5. Intervention: Patients received intrathecal baclofen infusions within 1mo following injury onset. Outcome Measure: Ashworth scores, Frequency, and Intensity of Autonomic Disorders.</p>	<ol style="list-style-type: none"> 1. Reductions in spasticity, and lower limb Ashworth scores at 6mo post intervention were reported in three of the four cases. In the last case, a substantial reduction in autonomic disorders and spasticity enabling passive physiotherapy was reported.
<p>Meythaler et al. (1999) USA Pre-Post N=17</p>	<p>Population: ABI; Mean Age=29yr; Gender: Male=14, Female=3. Intervention: Patients with spasticity and/ or dystonia were surgically fitted with an infusion pump into the lower abdominal wall for continuous administration of intrathecal baclofen (100µg/day). Patients were assessed at 1yr. Outcome Measure: Ashworth Rigidity Scale (ARS), Spasm Frequency Scale, Deep Tendon Reflex Score.</p>	<ol style="list-style-type: none"> 1. One year of intrathecal baclofen treatment (average dose: 302ug/d) resulted in a decrease in ARS (mean 2.2 points), spasm frequency (mean 1.6 points), and reflex scores (mean 2.4 points) for the lower extremity (all p<0.0001) 2. For the upper extremity, the ARS, spasm frequency, and reflex scores decreased by a mean of 1.4, 1.0, and 1.2 points respectively (all p<0.0001). 3. No cognitive side effects were observed after 1yr.
<p>Meythaler et al. (1999) USA Pre-Post N=6</p>	<p>Population: TBI=3, Stroke=3; Mean Age=50yr; Gender: Male=2, Female=4. Intervention: Patients were surgically fitted with a programmable infusion pump into the lower abdominal wall for continuous administration of baclofen using the same methodology as Meythaler et al. (1997). Outcome Measure: Ashworth Rigidity Scale, Spasm Frequency Scale, Deep Tendon Reflex scores.</p>	<ol style="list-style-type: none"> 1. Lower extremities showed a significant reduction in Ashworth scores (p<0.0001), affected lower limb reflex score (p=0.021), normal side (p=0.0051), but not significant changes in affected lower limb spasm score (p=0.500). 2. Upper extremities showed significant reductions in Ashworth scores on affected side (p=0.0002) but were not significant for Biceps Reflex score (affected and normal: p=0.109 and p=0.068), or spasm score (affected: p=0.1797). 3. No patients complained of subjective weakness on the normal side.
<p>Meythaler et al. (1997) USA Pre-Post N=12</p>	<p>Population: TBI=9, ABI=3; Mean Age=28yr; Gender: Male=11, Female=1. Intervention: Patients received continuous intrathecal baclofen delivery for 3mo via an implanted infusion pump-catheter system. Outcome Measure: Ashworth Rigidity Scale, Spasm Frequency Score, Deep Tendon Reflex Score.</p>	<ol style="list-style-type: none"> 1. For the lower extremity, Ashworth Scale Scores decreased by a mean of 1.4 points, spasm frequency by 1.5, and reflex scores by 2.5 (all p<0.0001). 2. For the upper extremity, the mean decrease in scores was 1.4 points for the Ashworth Scale (p=0.003), 1.2 for spasm frequency (p=0.007) and 1.0 for reflex (p=0.011).
<p>Becker et al. (1997) Germany Case Series N=18</p>	<p>Population: TBI=9, Hypoxic Brain Injury=9; Mean Age=41yr; Gender: Male=13, Female=6; Mean Time Post Injury=11.6mo. Intervention: Patients received continuous intrathecal baclofen infusion. Outcome Measure: Ashworth Scale, Spasm Frequency Scale.</p>	<ol style="list-style-type: none"> 1. In all patients, spasticity was reduced. 2. Mean Ashworth scores reduced from 4.5 to 2.33, and the mean spasm frequency scores decreased from 2.16 to 0.94. 3. Reduction in spasticity led to a reduction in pain.

Discussion

Meythaler et al. (1996) confirmed the effectiveness of intrathecal baclofen in decreasing upper and lower extremity spasticity in a randomized, double blinded, placebo controlled cross-over trial. In subsequent studies, the same investigators went on to demonstrate the effectiveness of intrathecal baclofen for decreasing spasticity for up to three months (Meythaler et al., 1997) and 1 year (J. M. Meythaler et al., 1999). Investigations carried out by other research groups have reported similar findings regarding the efficacy of intrathecal baclofen for the management of spasticity post ABI (Becker et al., 1997; Chow et al., 2015; Dario et al., 2002; Francisco et al., 2005; Hoarau et al., 2012b; Margetis et al., 2014; Posteraro et al., 2013; Stokic et al., 2005; Wang et al., 2016). However, a common limitation of these studies is the lack of a control group. Regardless, it appears that intrathecal baclofen is an effective treatment for spasticity. It should be noted, however, that some adverse effects, such as urinary hesitancy, were reported. Hoarau et al. (2012a) conducted a 10-year follow up of individuals with dysautonomia and hypertonia treated with intrathecal baclofen therapy. The study found that 62.8% of participants had some type of complication, with infections at the operative site being the most common (20.9%), followed by overdosed with profound flaccidity, sedation, and vomiting (16.3%) (Hoarau et al., 2012a).

Studies have also evaluated the functional consequences by assessing walking performance, gait speed, and range of motion following a bolus injection of intrathecal baclofen (Chow et al., 2015; Horn et al., 2010; Horn et al., 2005). Horn et al. (2005) found that although the injections produced changes in joint range of motion during gait, only ankles showed a significant result. Chow et al. (2015) similarly found an increase in ankle range of motion but found no significant differences in terms of gait speed, stride length, cadence, or stance. Future studies should be conducted using a prospective controlled trial or RCT study design that includes control groups to further establish the efficacy of intrathecal baclofen for the management of spasticity post ABI.

Conclusions

There is level 1b evidence (from one randomized controlled trial; Meythaler et al., 1996) that bolus intrathecal baclofen injections may produce short-term (up to six hours) reductions in upper and lower extremity spasticity compared to placebo following ABI.

There is level 4 evidence (from five case series; Wang et al., 2016; Becker et al., 1997; Francois, 2001; Francisco et al., 2005; Stokic et al., 2005; six pre-post tests; Dario et al., 2002; Margetis et al., 2014; Meythaler et al., 1997; 1999a; 1999b; Posteraro et al., 2013; and one post-test; Hoarau et al., 2012a) that intrathecal baclofen may result in long-term reductions in spasticity in both the upper and lower extremities following an ABI.

There is level 4 evidence (from three pre-post tests; Chow et al., 2015; Horn et al., 2005; 2010) that intrathecal baclofen may reduce spasticity and improve walking performance in ambulatory patients with ABI.



KEY POINTS

- Bolus injections of intrathecal baclofen likely produce short-term reductions in upper and lower extremity spasticity and improvements in walking performance post ABI.
- Intrathecal baclofen may reduce upper and lower extremity spasticity long-term post ABI.

Casting

Spasticity frequently results in musculoskeletal contractures (Mayer et al., 1997) and has been estimated in one study to have an incidence as high as 84% in patients with TBI (Yarkony & Sahgal, 1987). As with hand splinting, the theoretical premise for the effect of casting on hypertonia and joint mobility is based on different neurophysiological and biomechanical principles (Mortenson & Eng, 2003). Spasticity may be reduced by the effect of prolonged stretch, or possibly the effects of neutral warmth or prolonged pressure which may in turn reduce the cutaneous sensory input to the spinal cord. From a biomechanical perspective, muscle and connective tissues are likely elongated when immobilized in a stretched position, thus reducing the incidence on contractures (Mortenson & Eng, 2003).

Casting has been thought to reduce hypertonia and spasticity in individuals with an ABI. This is believed to be the result of reducing contractures by stretching the muscles of the immobilized limb (Pohl et al., 2002). Serial casting is a process in which the angle of the cast is changed periodically, with the objective of returning the joint to its original angle. However, despite the fact that serial casting has been utilized by physiotherapists for more than 40 years there is little empirical data to support its use in isolation. Conversely, evidence exists supporting the use of casting as a useful adjunct to other therapies for the management of spasticity and contracture in patients post TBI.

TABLE 19 | Casting Techniques for the Treatment of Spasticity Post ABI

Author, Year Country Study Design Sample Size	Methods	Outcome
<p>Moseley et al. (2008) RCT PEDro=8 N=26</p>	<p>Population: TBI; <i>Positioning Group (n=12):</i> Gender: Male=11, Female=1; Mean Age=30.8yr; Median Time Post Injury=71d; Median Glasgow Coma Scale (GCS) score=3. <i>Serial Casting Group (n=14):</i> Gender: Male=12, Female=2; Mean Age=32.3yr; Median Time Post Injury=59d; Median GCS score=4.5. Intervention: Participants were randomized to one of two interventions for elbow flexion contracture: serial casting or passive stretch (positioning group). Those in the serial casting group had long arm synthetic casts applied for</p>	<ol style="list-style-type: none"> 1. Stretching group received a mean of 13 hr of stretching during the intervention and the serial casting had stretch applied for a mean of 13.6 days. 2. Those in the serial casting group had a greater reduction in contracture in the short term: serial casting reduced contracture by a mean of 22° (p<0.001) when compared to the positioning group. The next day the mean reduction was only 11° for the casting group, and differences between groups were less (p=0.052).

	<p>2wk with the elbow in a stretched position. Casts were changed to progress the stretch. After 2wk, the cast was removed, and the participants underwent passive stretching 1hr/wk for 4wk. The second group had passive stretch applied to the elbow flexor muscles for 1hr/day, 5 x/wk.</p> <p>Outcome Measure: Torque controlled passive elbow extension, Modified Tardieu Scale.</p>	<ol style="list-style-type: none"> At follow up assessment, there was no significant or clinically meaningful difference between groups (mean effect 2°, p=0.782). When looking at spasticity the serial casting group had slightly lower spasticity than the stretching group (p<0.05).
<p>Moseley (1997) Australia RCT PEDro=4 N=9</p>	<p>Population: TBI; Mean Age=29.1yr; Gender: Male=8; Female=1; Time Post Injury=72.2d.</p> <p>Intervention: Participants in the experimental group received a below-knee cast and stretched for 7d. The control group did not receive a cast or stretching. Participants then received the other intervention.</p> <p>Outcome Measure: Passive ankle dorsiflexion (PAD) movement.</p>	<ol style="list-style-type: none"> PAD movement increased (mean: 13.5°) during intervention compared to a decrease (mean: 1.9°) shown for the control condition (p<0.05). Mean difference between conditions was 15.4°.
<p>Singer et al. (2003) Australia Pre-Post N=9</p>	<p>Population: Stroke=3, Subarachnoid Hemorrhage=4, Intra-cerebral Hemorrhage=1, Diffuse Axonal Injury=1; Mean Age=30.7yr; Gender: Male=6, Female=3; Mean Time Post Injury=3.9mo.</p> <p>Intervention: A serial casting procedure addressing extensibility, passive resistance torque and stretch reflex response of the ankle was implemented. Casts were applied weekly and continued until goal was reached or no measurable gain recorded.</p> <p>Outcome Measure: Maximal Passive Range of Motion, Transfer Dependency, and Rancho Los Amigos Levels of Cognitive Functioning (RLA).</p>	<ol style="list-style-type: none"> Post-casting, all individuals had at least 10° dorsiflexion with the knee flexed and 6 had maximal passive range of motion of 10° dorsiflexion with knee extended. Muscle extensibility and passive torque improved significantly (p<0.0001). Functional range was maintained in 8 participants at 6mo follow-up. All participants improved RLA scores by at least one point. Significant improvements were noted for transfer dependency scores from initial to post intervention (p<0.0015). Casting did lead to some tissue breakdown.
<p>Pohl et al. (2002) Germany Case Control N=105</p>	<p>Population: TBI=43, Stroke=19, Intracerebral Hemorrhage=19, Cerebral Hypoxia=11, Subarachnoid Hemorrhage=6, Other=7; Gender: Male=81, Female=24. <i>Control Group (n=56):</i> Median Age=38.2yr. <i>Intervention Group (n=49):</i> Median Age=44.6yr.</p> <p>Intervention: A stepwise reduction of fixed, flexed joint contracture via serial casting. Patients were treated with conventional casting changing intervals of 5-7d (control) or 1-4d (Intervention), to maximum possible extension (<10% of extension deficit) or when extension deficit fails to reduce after two cast changes.</p> <p>Outcome Measure: Maximum deficits of different joints (elbow, wrist, knee, ankles), Range of Motion (ROM), Number of Complications.</p>	<ol style="list-style-type: none"> The median change interval was 6.9 days for 92 joints of 56 control group patients. The median change interval was 2.7 days for 80 joints of 49 intervention group patients. Mean casting time in the control and intervention group was 32.6±20.6 days and 9.3±5.6 days, respectively. ROM improved after casting and 1mo follow-up in both groups (p<0.001) but no between group differences were found (p=0.72). Casting complications differed between groups 1 and 2 (29.3% versus 8.8%, p=0.001).

Discussion

In comparison to passive stretching, serial casting was beneficial in improving contracture of the elbow (Moseley et al., 2008). The improvement in contracture, however, was no longer significant after 4

weeks. In addition, the researchers noted a greater improvement in spasticity in the casting group when compared to the stretching group. The results from this study suggest that while serial casting may be effective initially, it does not appear to have long-term effects on contractures.

In order to evaluate the efficacy of lower extremity casting post ABI, Moseley (1997) used a randomized open cross-over design to compare one week of casting combined with stretching to a week of no therapy (control) for ankle plantar flexion contractures. The experimental group had a significantly improved range of passive ankle dorsiflexion whereas the control group tended to have overall deterioration of ankle range of motion (Moseley, 1997). In two separate studies, Singer et al. (2003) and Singer et al. (2003) also evaluated the efficacy of weekly casting and found casting to be effective in improving ankle movement. In addition, greater ankle mobility was shown to be associated with improved transfer independence (Singer et al., 2003). It should be noted, however, that casting can lead to tissue breakdown (B. J. Singer et al., 2003).

In a retrospective case comparison study, Pohl et al. (2002) compared short, one to four days casting to a longer duration, five to seven days casting, for both upper and lower extremity joints. Although improvements in range of motion were seen in each group immediately following the intervention and at a one-month follow-up, there was no significant difference found between groups. However, the discontinuation rate in the longer duration group due to complications was significantly higher than for the short casting interval group.

Conclusions

There is level 1b evidence (from one randomized controlled trial; Moseley et al., 2008) that serial casting may improve contractures of the elbow initially, but not long-term, when compared to passive stretching in individuals with an ABI.

There is level 1b evidence (from one randomized controlled trial; Moseley et al., 2008) that serial casting may be superior to passive stretching at improving spasticity of the elbow in individuals post ABI.

There is level 2 evidence (from one randomized controlled trial; Moseley, 1997) that a below-knee casting and stretching protocol may increase passive ankle dorsiflexion in patients post ABI.

There is level 4 evidence (from one pre-post test; Singer et al., 2003) that weekly below-knee casts may improve ankle range of motion, muscle extensibility, and passive torque in patients post ABI.

There is level 3 evidence (from one case control study; Pohl et al., 2002) that short duration (one to four days) and longer duration (five to seven days) serial casting may have similar effects on upper or lower extremity range of motion in individuals post ABI.



KEY POINTS

- Serial casting likely improves contractures and spasticity in individuals with an ABI compared to stretching, however, contracture improvement may not be maintained long-term.
- Below-knee casting and stretching might increase passive ankle dorsiflexion in patients post ABI.
- Serial below-knee casting may improve ankle range of motion and muscle extensibility in patients post TBI, however, this intervention may be associated with tissue breakdown.
- Serial casting, whether for a short or long duration, might improve range of motion in individuals with an ABI. However, short duration casting may have a lower complication rate than long duration.

Adjustable Orthosis

Similar to casting, an adjustable pre-fabricated orthosis could potentially provide prolonged stretching of an ankle plantar flexion contracture. Advantages of the orthosis over a rigid cast include the ease of adjustability and the ability to remove it daily for short periods of time. A pre-post study by Grissom and Blanton (2001) examined six participants with mixed etiologies who received a 2% lidocaine block of the posterior tibial nerve and then wore an adjustable ankle-foot orthosis on the affected ankle for 23 hours per day for two weeks for plantarflexion contractures. Adjustments were attempted every two to three days to increase passive dorsiflexion range of motion. The group reported a significant mean gain in ankle dorsiflexion of 20.1° (p=0.0078). Of concern, there was a relatively high complication rate of skin breakdown and pain that occurred with splinting (44%). Further, the only individual with a TBI dropped out as the orthosis was thought to agitate the individual (Grissom & Blanton, 2001). As a result, more research is needed with an ABI population before conclusions on adjustable orthoses can be made.

Hand Splinting and Stretching

Hand splinting and stretching is another way that patients may experience relief from spasticity and contracture post ABI. The study below examines the effectiveness of combination splinting and stretching for spasticity relief (Table 20).

TABLE 20 | Hand Splinting and Stretching for the Treatment of Spasticity Post ABI

Author, Year Country Study Design Sample Size	Methods	Outcome
Thibaut et al. (2015) Belgium RCT PEDro=4 N=17	Population: TBI=7, Anoxia=5, Aneurysm=5; Mean Age=41yr; Gender: Male=9, Female=8; Mean Time Post Injury=35mo; Severity: Severe. Intervention: Participants were randomized to receive one of the following exercise protocols	1. In G1, there were no significant changes in MAS, MTS, ROM, or HO after stretching or after the control protocol. 2. In G2, the mean MAS score of flinger flexor muscles improved significantly after

	<p>on each of their upper limbs: manual stretching and control (no Intervention) (G1, n=8), soft splinting and control (G2, n=12), or soft splinting and manual stretching (G3, n=14). Each exercise was done for 30min followed by a 60min break. Outcomes were assessed before (T1) and after (T2) each protocol, and after each break (T3).</p> <p>Outcome Measures: Modified Ashworth Scale (MAS), Modified Tardieu Scale (MTS), Range of Motion (ROM), and Hand Opening (HO).</p>	<p>splinting from T1 to T2 ($p=0.014$) and the improvement was maintained at T3 ($p=0.022$). There was no significant change for the control.</p> <ol style="list-style-type: none"> 3. In G3, the mean MAS score of finger flexor muscles improved significantly after both splinting ($p=0.014$) and stretching ($p=0.022$) from T1 to T2, but neither improvement was maintained at T3. 4. In G2, the mean HO score improved significantly after splinting from T1 to T2 ($p=0.009$), but the improvement was not maintained at T3. There was no significant change for the control. 5. In G3, the mean HO score improved significantly after splinting ($p=0.005$) from T1 to T2, but the improvement was not maintained at T3. There was no significant change in mean HO score after stretching ($p=0.249$). 6. In G3 and G2, there were no significant changes in MTS or ROM after the interventions.
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Discussion

A randomized controlled trial compared manual stretching, soft hand splinting, and manual stretching plus soft hand splinting to determine the optimal intervention (Thibaut et al., 2015). Results suggested that soft hand splinting for 30 minutes resulted in improved hand opening and reduced spasticity of the flexor finger muscles, however, improvements in hand opening were not maintained after the break period. The hand splint was said to be feasible to use in daily care, as the splint was comfortable and easy to apply. There is a need to further research the effect of splinting in individuals with ABI as this practice is used in both acute and rehabilitation settings.

Conclusions

There is level 1b evidence (from one randomized controlled trial; Thibaut et al., 2015) that nocturnal hand splinting may not improve upper extremity range of motion or function compared to standard care in individuals post ABI.



KEY POINTS

- Hand splinting combined with stretching may be an effective treatment for spasticity and range of motion.

Multimodal Interventions

Multimodal interventions can consist of combining two or more interventions or comparing different interventions to each other. The following studies use a multimodal approach to determining effective interventions for the treatment of spasticity post ABI (Table 21).

TABLE 21 | Multimodal Interventions for the Treatment of Spasticity Post ABI.

Author, Year Country Study Design Sample Size	Methods	Outcome
<p>Leung et al. (2014) Australia RCT PEDro=8 N_{initial}=35, N_{Final}=32</p>	<p>Population: TBI; <i>Experimental Group (EG; n=17)</i>: Mean Age=38yr; Gender: Male=14, Female=3; Mean Time Post Injury=140d; Mean GCS=5. <i>Control Group (CG; n=18)</i>: Mean Age=38yr; Gender: Male=15, Female=3; Mean Time Post Injury=83d; Mean GCS=5. Intervention: Participants were randomly allocated to either the EG or CG group. The EG group underwent a treatment of tilt table standing and electrical stimulation (30 min 5d/wk) and splinting (12hr 5d/wk) for a total of 6 wk. For the next 4wk EG group participants underwent tilt table standing alone (30 min 3d/wk). The CG group underwent tilt table standing (30min 3d/wk) for the full 10 wk. Measures were taken at baseline, 6wk and 10wk. Outcome Measure: Passive ankle dorsiflexion, Functional Independence Measure (FIM).</p>	<ol style="list-style-type: none"> 1. The CG group had a greater range of motion for passive ankle dorsiflexion than the EG group at 6 wk (3 degrees) and 10 wk (-1 degree). 2. The EG group had a greater mean reduction in spasticity (1 point) at 6 wk; however, the effect disappeared at 10 wk. 3. There was no between group differences in walking speed. 4. There were no differences between groups for tolerance to treatment, perceived treatment benefit, perceived treatment worth, and willingness to continue with treatment.
<p>Lorentzen et al. (2012) Denmark RCT-Crossover PEDro=6 N=10</p>	<p>Population: TBI=6, Stroke=2, Subarachnoid Hemorrhage=1, Post-Operative Hemorrhage=1; Mean Age=31.5yr; Gender: Male=6, Female=4; Mean Time Post Injury=3.6mo. Intervention: Participants received either Neural Tension Technique (NTT) intervention or the Random Passive Movement (RPM) treatment on knee joints. The NTT and RPM treatments lasted for 20min, with clinical tests conducted immediately before and after each intervention. Outcome measure: Modified Ashworth Scale (MAS), Range of Motion (ROM).</p>	<ol style="list-style-type: none"> 1. The blinded reviewers found no significant change on the MAS for knee flexors after the NTT (Mean change=0.4–0.6, p=0.10–0.31) or the RPM (Mean change=0.4–0.5, p=0.1–0.3). No significant between group differences were found (p=0.12-0.71). 2. No significant between or within group differences were found based on the MAS for knee extensors after the intervention. The blinded reviewers found no significant difference in ROM after RPM (p=0.13) but did for NTT (p<0.05). No significant between group differences for ROM were found (p>0.32).

Author, Year Country Study Design Sample Size	Methods	Outcome
<p>Verplancke et al. (2005) UK RCT PEDro=4 N=35</p>	<p>Population: TBI=20, Neurosurgery=11, Anoxia=4; Gender: Male=25, Female=10. <i>Group 1 (n=11):</i> Median Age=40yr; Mean Time Post Injury=9.3d, Mean Glasgow Coma Scale (GCS) score 4.3. <i>Group 2 (n=12):</i> Median Age=33.5yr; Mean Time Post Injury=13.25 days; Mean GCS score=4.7. <i>Group 3 (n=12):</i> Median Age=41.5yr; Mean Time Post Injury=10.6d; Mean GCS score=5.2.</p> <p>Intervention: Participants entered one of three groups: group 1 received a physical intervention (controls), group 2 received casting plus injections of saline (4 ml), and group 3 received casting with botulinum toxin (100 units per leg) into the gastrocnemius and soleus muscles. Patients were re-cast if a 10° change in dorsiflexion occurred.</p> <p>Outcome Measure: Calf contracture, Modified Ashworth Scale (MAS), Passive Range of Motion.</p>	<ol style="list-style-type: none"> Eighty-eight percent of patients developed spasticity within 14 days of injury. Mean change in angle of passive ankle dorsiflexion was 4.59° in controls, 11.69° in group 2 and 13.59° in group 3. There were significant improvements in MAS scores in treated groups (group 2, p<0.03; group 3, p=0.04) but not controls (p>0.05).
<p>Leung et al. (2019) Australia RCT PEDro=7 N_{Initial}=13, N_{Final}=11</p>	<p>Population: TBI=13; <i>Intervention Group (n=7):</i> Median Age=27yr (27-57); Gender: Male=3, Female=7; Median Time Post Injury=125d (78-150); Severity: Median GCS=3 (3-4). <i>Control Group (n=6):</i> Median Age=39yr (28-53); Gender: Male=3, Female=3; Median Time Post Injury=113d (73-159); Severity: Median GCS=9 (3-9)</p> <p>Intervention: Participants in the intervention group received botulinum toxin injections and serial casting, while those in the control group were placed on a waiting list for six weeks and then received the same intervention. Both groups received splinting and motor training following serial casting. Outcome measures were assessed at baseline, completion of casting, 2 and 8wk after casting.</p> <p>Outcome Measures: Passive ankle dorsiflexion range, spasticity, ankle dorsiflexor strength, Functional Independence Measure (FIM).</p>	<ol style="list-style-type: none"> Passive ankle dorsiflexion range significantly improved following completion of casting (26°, 95% CI: 20-31) and improvements were sustained at 2 (26°, 95% CI: 18-33) and 8wk (24°, 95% CI: 19-30) following casting. No significant between groups differences were observed for strength and spasticity (p>.05).

Discussion

For the lower extremity, Verplancke et al. (2005) found that active prophylaxis of leg spasticity using casting was beneficial, however, there was no difference in outcomes between those casted with or without Botulinum toxin. Another study by Leung and colleagues' (2019) revealed no significant between-group differences in spasticity post intervention between patients who received serial casting,

botulinum toxin injections, motor training, and splinting and waitlist controls who received standard care with no botulinum toxin injections. Leung and colleagues (2019), however, did observe a greater improvement joint range in the intervention group compared to the control group. Future studies, with a larger sample size, are needed to further examine the efficacy of casting combined with botulinum toxin injections in managing spasticity in individuals with ABI.

Electrical stimulation was then studied as a multimodal intervention, combined with standing on a tilt table, and splinting for ankle contractures (Leung et al., 2014). This RCT found improvements in passive ankle dorsiflexion that favoured the control group, however, neither group reached values of clinical significance. Leung et al. (2014) did find a significant reduction in spasticity favouring the intervention group at week 6 but it no longer existed by week 10. Of note, 10 participants had issues with adhering to the tilt table procedure due to fainting, fatigue, or behavioural issues. In addition, since the experimental group received a combination of 3 treatments (tilt table, electrical stimulation, and casting), while the control group only underwent tilt table treatment, it is unclear which intervention was responsible for the short-term reduction in spasticity in the experimental group.

In a RCT by Lorentzen et al. (2012), participants received either neural tension technique (NTT) treatment or random passive movement (RPM) therapy on knee joints. No significant changes in spasticity were observed between groups in the knee flexor or extensor muscles. Furthermore, range of motion may be improved to the same effect by NTT and RPM therapies Hirose et al. (2013).

Conclusions

There is level 1b evidence (from one randomized controlled trial; Leung et al., 2014) that electrical stimulation in combination with tilt table standing and splinting may decrease spasticity at 6 weeks post intervention compared to tilt table standing alone in patients with an ABI.

There is level 2 evidence (from one randomized controlled trial; Verplancke et al., 2005) that botulinum toxin combined with casting may not be more effective than botulinum toxin injections alone in improving leg spasticity in individuals with an ABI.

There is level 1b evidence (from one randomized controlled trial; Lorentzen et al., 2012) that neural tension technique may not be more effective than random passive movement in improving lower extremity spasticity and range of motion in individuals with an ABI.

There is level 1b evidence (from one randomized controlled trial; Leung et al., 2019) that a program for contracture management consisting of serial casting, botulinum toxin, motor training and splinting may improve joint range but not improve spasticity in individuals with moderate to severe TBI.

KEY POINTS

- Botulinum toxin injections in combination with casting may be as effective as casting alone at reducing leg spasticity in patients post ABI.
- Electrical stimulation in combination with tilt table standing and splinting may acutely improve spasticity (6 weeks) in patients post ABI.
- Neural tension technique may be just as effective as random passive movement for improving lower extremity spasticity post ABI.
- A program for contracture management consisting of serial casting, botulinum toxin, motor training and splinting may improve joint range but not improve spasticity in individuals with moderate to severe TBI.

Visual Dysfunction

Dysfunctions of the visual system are quite common following TBI (Morton, 2004). The overall incidence of cranial nerve injury in individuals hospitalized following TBI has been reported to be 19% (Bontke et al., 1993). It is a relatively new concept that the visual system can respond to treatments directed towards visual-perceptual and/or visual motor skills in individuals with acquired neurological damage. The visual system is highly integrated with many functions other than sight, as it also acts as a primary sensory receptor for motor, social, cognitive, communicative, and emotive tasks. Improvements in visual-perceptual and visual-motor disorders can increase function in all the aforementioned areas and can enhance maximal functional recovery. Consequently, it is necessary to direct a fair amount of attention to visual system disorders in individuals with TBI and this aspect should be considered an essential part of any rehabilitation program (Morton, 2004).

In a review conducted by Riggs et al. (2007), the authors noted that visual rehabilitation studies have primarily involved stroke patients and have largely neglected the TBI population. Their review indicates that visual neglect disorders resulting from a stroke and brain injury show improvement after treatment with prisms, visuomotor feedback training, and patching interventions. Moreover, a review by Berger et al. (2016) examined specific interventions for improving occupational performance in adults with visual impairments as a result of TBI. Results indicate that there is limited evidence on the effectiveness of vision therapy for oculomotor dysfunction, however, there is sufficient evidence to support vision therapy as a method to improve visual field deficits in patients with TBI (Berger et al., 2016) (Table 22).

TABLE 22 | Interventions for the Treatment of Visual Dysfunction Post ABI

Author, Year Country Study Design Sample Size	Methods	Outcome
<p>Kasten et al. (2000) Germany RCT PEDro=5 N=32</p>	<p>Population: Vascular Disease=9, ABI=23; Mean Age=51.1yr; Gender: Male=20, Female=12; Mean Time Post Injury=6.8yr. Intervention: Participants were randomly assigned to either the Control Group (foveal fixation training only - FixTrain) or Restitution Group (PC-based training program – Visure, SeeTrain). Both groups trained for 1hr/day at home for ≥150hr over a 6mo period. Outcome Measure: High-Resolution Campimetry (PeriMa), Conventional Perimetry (TAP-2000), Pattern Recognition (PeriForm), Colour Discrimination (PeriColor).</p>	<ol style="list-style-type: none"> 1. The restitution group showed an increase in PeriMa and TAP-2000 after training (p<0.01 and p<0.04, respectively). 2. The restitution group had non-significant improvements in PeriForm and PeriColor (p=0.06 and p=0.12, respectively) within the defective area of the visual field. 3. There was a correlation between PeriMa and PeriForm (r=0.67, p<0.05) and PeriForm and PeriColor (r=0.37, p<0.05) for improved color and form perception. 4. The PeriMa, PeriForm, and PeriColor all demonstrated a shift of the visual field border in the direction of the blind area for participants in the restitution group.
<p>Kasten et al. (1998) Germany RCT PEDro=7 N=38</p>	<p>Population: Stroke=10, ABI=28; Mean Age=51.5yr; Gender: Male=24, Female=14; Mean Time Post Injury=7.0mo. Intervention: Participants were randomly assigned to either the Restitution Group (visual restitution training (VRT)) or the Control Group (fixation training program which required eye movement toward stimuli within the foveal region). Both groups completed 150hr of training over 6mo at home in a darkened room. Outcome Measure: High-Resolution Perimetry (HRP), Response Frequency, Area of Absolute Defect, Tübinger Automatic Perimeter 2000 (TAP).</p>	<ol style="list-style-type: none"> 1. Performance on HRP showed improved ability to perceive visual stimuli above detection threshold in the VRT group post-training (post-chiasmic: p<0.05, optic nerve: p<0.01). 2. The VRT group demonstrated a higher response frequency to stimuli than the control group (p<0.05). 3. TAP scores showed a decrease in the area of absolute defect for participants in the VRT group with optic nerve injuries (p<0.01). 4. Participants with optic nerve damage benefitted most from VRT; 72.2% of participants who received VRT reported subjective improvement while only 16.6% of the control group participants did so (p<0.03).
<p>Conrad et al. (2017) USA Pre-Post N_{Initial}=19, N_{Final}=13</p>	<p>Population: TBI=15, Stroke=3, Organic Brain Syndrome=1; Mean Age=45.2yr; Gender: Male=12, Female=7; Time Post Injury=2.2 yr. Intervention: Participants were prescribed home-based computer vergence therapy using software provided (5d/wk for 12wk). Participants were assessed at baseline, 4, 8 and 12wk. Outcome Measure: Negative Fusional Vergence, Positive Fusional Vergence, Near Point of Convergence, Vergence Facility, Convergence Insufficiency Symptom Survey (CISS).</p>	<ol style="list-style-type: none"> 1. Negative fusional vergence showed significant improvement over 12wk in blur (p=0.037), break (p=0.003) and recovery (p=0.006). 2. Positive fusional vergence showed significant improvement over 12wk in blur, break and recovery (p<0.0001). 3. Near point of convergence showed significant improvement over 12wk in break (p=0.002) and recovery (p<0.001). 4. Vergence facility showed a significant improvement from baseline to 12wk (p<0.0001). 5. CISS scores improved significantly from baseline to 12wk (p=0.0001).

<p>Doble et al. (2010) USA Pre-Post N=43</p>	<p>Population: TBI; Mean Age=44yr; Gender: Male=12, Female=31; Mean Time Post Injury=3.6yr. Intervention: Patients were given individualized prismatic spectacle lenses. Outcome Measures: Vertical Heterophoria Symptom Questionnaire (VHS-Q).</p>	<ol style="list-style-type: none"> 1. The mean VHS-Q score at baseline was 34.8 ±16.1 (scale ranges 0-75 points). 2. The mean difference in VHS-Q scores pre to post intervention was 16.7 ± 12.8 (p<0.01).
<p>Ciuffreda et al. (2006) USA PCT N=14</p>	<p>Population: TBI=9, Stroke=5; Mean Age=48.4yr; Gender: Male=9, Female=5; Mean Time Post Injury=2.4yr. Intervention: Patients with oculomotor-based dysfunction received reading-related rehabilitation. Participants were assigned to either Visual (V) Feedback Training (modes included normal internal oculomotor visual feedback in isolation - T1 for 4 weeks) or combined Visual and Auditory (V+A) Feedback (concurrent with external oculomotor auditory feedback - T2 for 4wk) with a cross-over design. Participants underwent single-line (SL) and multiple-line (ML) simulated reading, and basic versional tracking (fixation, saccade, and pursuit) 2x/wk for an 8wk period. Outcome Measure: Simulated Reading, Visagraph, Basic Versional Eye Movements, Reading Rating Scale.</p>	<ol style="list-style-type: none"> 1. Significant improvements were found for each of the five questions on the reading rating scale (p<0.01). 2. Simulated reading saccade ratio showed significant improvements for ML (T1: p<0.05) and SL (T1: p<0.01; T2: p<0.01) training compared to pre-training levels 3. The TBI subgroup had more improvements in the simulated reading and Visagraph. 8. There was a trend (0.05<p<0.10) for greater reading improvement in V+A Feedback training.
<p>Padula et al. (1994) USA Pre-Post N=20</p>	<p>Population: TBI=10, Healthy Control=10; Age Range=22-46yr; Gender: Male=8, Female=12. Intervention: Visual evoked potentials (VEP) were performed using Nicolet Compact Four Electrodiagnostic System and a Visual Stimulator over three trials. During the baseline trial, participants were tested without bi-nasal occluders and base-in prisms. In the experimental trial, participants were tested with bi-nasal occluders and two diopters of base-in prisms. In the last phase, the bi-nasal occluders and prisms were removed, and the participants were re-evaluated. Outcome Measure: Visual Evoked Potential (VEP).</p>	<ol style="list-style-type: none"> 1. The use of base-in prisms and bi-nasal occluders produced a large increase in VEP amplitude in individuals with TBI (p<0.01). 2. Using base-in prisms and bi-nasal occluders resulted in a significantly larger increase in VEP amplitude in individuals with TBI compared with the healthy controls (mean difference between groups 1.78, p<0.01).

Discussion

A small pre-post study reported that visual dysfunction post ABI can be corrected with base-in prisms, as they affect the ambient visual process by increasing the effectiveness of binocular cortical cells (Padula et al., 1994). Base-in prisms and bi-nasal occluders incorporated within the lenses of both eyes increase the amplitude of visual-evoked potentials (Padula et al., 1994). A different group suggested that prismatic spectacle lenses are also effective in reducing symptoms related to vertical heterophoria and

concussion, as they reduce the faulty vertical alignment signal generated by the brain injury (Doble et al., 2010).

Kasten et al. (1998) found that individuals with optic nerve or post-chiasmic injury associated with ABI who complete computer-based Visual restitution training (VRT) experience visual field enlargement and increased light detection. Furthermore, detection training has shown improvements in visual detection, as well as improvements in other visual functions such as shape and color recognition (Kasten et al., 2000). Conrad et al. (2017) studied a home-based computer vergence therapy program used to improve binocular visual dysfunction after ABI. Participants underwent home-based visual vergence therapy five days a week for 12 weeks. Negative vergence, positive vergence, near point convergence and vergence facility all showed significant improvements over the 12 week intervention period (Conrad et al., 2017).

When the reading dysfunction post ABI is a result of sensory-based hemifield deficits or neuromotor deficits, saccadic oculomotor rehabilitation can lead to improvements in eye movements which are required for accurate reading (Ciuffreda et al., 2006). Repetitive oculomotor conditioning reduces the cognitive and attentional load of reading and results in a structural and systematic approach to reading. The benefits of oculomotor rehabilitation were observed in other activities of daily living such as concentration and visual scanning. Most importantly, reducing visual deficits in patients post TBI may facilitate their involvement in other therapies and contribute to overall recovery (Ciuffreda et al., 2006).

Conclusions

There is level 1b evidence (from one randomized controlled trial; Kasten et al., 1998) and level 2 evidence (from one randomized controlled trial; Kasten et al., 2000) that computer-based restitution training may be effective in improving the vision of those who sustain a TBI compared to visual fixation training.

There is level 2 evidence (from one prospective controlled trial; Ciuffreda et al., 2006) that saccade visual tracking compared to fixation and pursuit tracking may improve single-line and multi-line reading post ABI.

There is level 4 evidence (from one pre-post test; Padula et al., 1994) that base-in prisms and bi-nasal occluders can be effective in treating ambient vision disturbances resulting from an ABI.

There is level 4 evidence (from one pre-post test; Doble et al., 2010) that prismatic spectacle lenses may be effective in reducing symptom burden in patients with vertical heterophoria and post-concussive symptoms post injury.

There is level 4 evidence (from one pre-post test; Conrad et al., 2017) that home-based visual vergence therapy be effective in treating binocular vision disorders in individuals with ABI.


 KEY POINTS

- **Computer based restitution training and rehabilitation programs directed at improving visual function likely improve the vision of those who sustain a TBI.**
- **Base-in prisms and bi-nasal occluders may be effective in treating ambient vision disturbances.**
- **Saccadic oculomotor rehabilitation may improve eye movements and reading in patients post ABI.**
- **Home-based visual vergence therapy be effective in treating binocular vision disorders in individuals with ABI.**

Vestibular Dysfunction

Vestibular dysfunction post TBI is a major contributor to reduced tolerance for rehabilitation and delayed recovery (Bhatnagar et al., 2019). Despite its high prevalence in the TBI population, vestibular dysfunction is commonly overlooked when diagnosing an individual with TBI. Vertigo, balance problems, visual complaints (double vision, blurriness), and nausea are possible symptoms of vestibular injury. The most common persisting vestibular symptom after TBI is positional vertigo, or vertigo caused by head movement. Vertigo is caused by dysfunction of the vestibular nerve or the labyrinth (Shepard & Telian, 1995) and the inability of the central nervous system to effectively compensate for the dysfunction (Gurr & Moffat, 2001). Provoked vertigo manifests as either unilateral peripheral hypofunction, bilateral peripheral hypofunction, or benign paroxysmal positional vertigo (BPPV) (Godbout, 1997).

Although it is common for spontaneous resolution of vertigo to occur within 6 months of onset, recovery in the TBI population is constricted due to the frequent combination of central and peripheral vestibular structure injury. Vestibular rehabilitation following TBI is therefore needed to promote vestibular adaptation and recovery. Techniques which are typically used in vestibular rehabilitation are gaze stability exercises, vestibulo-ocular reflex gain adaptation, substitution exercises, habituation techniques, and static and dynamic balance and gait exercises (Scherer & Schubert, 2009). The optimal recovery of vestibular dysfunction is thought to be based on selecting the appropriate vestibular exercises for a specific individual and progressing gradually through the assigned exercises while increasing difficulty and intensity (Wee, 2002). The literature includes a variety of interventions for vestibular rehabilitation (Table 23).

TABLE 23 | Interventions for the Treatment of Vestibular Dysfunction Post ABI

Author, Year Country Study Design Sample Size	Methods	Outcome
<p>Naguib & Madian (2014) Egypt RCT PEDro=5 N=60</p>	<p>Population: TBI; Mean Age=30yr; <i>Group 1 (n=20):</i> Gender: Male=14, Female=6; Severity: Mild=8, Moderate=7, Severe=5. <i>Group 2 (n=20):</i> Gender: Male=14, Female=6; Severity: Mild=8, Moderate=8, Severe=4. <i>Group 3 (n=20):</i> Gender: Male=15, Female=5; Severity: Mild=6, Moderate=8, Severe=6.</p> <p>Intervention: Participants were randomized to receive betahistidine dihydrochloride (48mg/d, Group 1), a vestibular rehabilitation program (Group 2), or both (Group 3) as treatment for a balance disorder. Outcomes were assessed via videonystagmography at baseline, 1 and 2wk, and then every month until recovery.</p> <p>Outcome Measures: Recovery time.</p>	<ol style="list-style-type: none"> Group 3 showed the earliest recovery time: complete recovery within 2mo. For Group 2, 80% had complete recovery within 2 months and 20% within 3mo. For Group 1, 85% had complete recovery within 2-3 months, and 15% in more than 3 months. Mean recovery time was significantly longer in Group 1 (62.1d) than in Group 2 (37.6d) and Group 3 (34.4d; p<0.050), but there was no significant difference between Group 2 and Group 3 (p>0.05).
<p>Peirone et al. (2014) Italy RCT PEDro=6 N=16</p>	<p>Population: TBI=7, Stroke=7, Other=2; Mean Age=40.5yr; Gender: Male=9, Female=7; Mean Time Post Injury=14.3mo.</p> <p>Intervention: Participants were randomized into a control (n=8) or intervention group (n=8). Both groups received standard physiotherapy in 50min sessions (3x/wk for 7wk). The intervention group also performed an individualized dual-task home-based programme (6d/wk for 7wk).</p> <p>Outcome Measure: Balance Evaluation System Test (BEST), Activities-Specific Balance Confidence Scale, Goal Attainment Scaling (GAS).</p>	<ol style="list-style-type: none"> Post-intervention scores differed significantly between groups on the BEST, with the intervention group improving more (p=0.008). There were no significant between group differences on the Activities-specific Balance Confidence Scale (p=0.110), or the GAS (p=0.093). The control group made significant improvements on the BEST (mean change=5.5±3.53, p=0.020) and the GAS (mean change=16.28±6.58, p=0.010). The intervention group made significant improvements from pre to post intervention on the BEST (mean change=17.87±6.05, p=0.014), the Activities-Specific Balance Confidence scale (mean change=25.25±25.51, p=0.01) and the GAS (mean change=19.37±9.03, p=0.02).

Author, Year Country Study Design Sample Size	Methods	Outcome
<p>Motin et al. (2005) Israel Post-Test N=10</p>	<p>Population: Severe TBI; Mean Age=43yr; Gender: Male=8, Female=2; Mean Time Post Injury=67d. Intervention: Patients underwent a particle reposition maneuver. The examiner performed the Dix-Hallpike test to the affected side such that nystagmus and vertigo were elicited; this position was maintained for 1-2min. The patient's head was then rotated 90° to the opposite side and held for ~ 30sec. The participant was then asked to turn their head another 90° to the unaffected side. This position was maintained for another 1-2min and then the participant was assisted to sit-up. Outcome Measure: Improvements in Positional Nystagmus.</p>	<ol style="list-style-type: none"> Six of 10 participants had resolved positional nystagmus and vertigo following a single particle repositioning maneuver. Nine of 14 (64%) affected ears had resolved positional nystagmus and vertigo following a single particle repositioning maneuver. The other four participants needed between 3 and 6 repeated treatments until their symptoms were completely resolved.
<p>Dault and Duga (2002) Canada PCT N=8</p>	<p>Population: TBI=8; Mean Age=29.6yr; Gender: Male=6, Female=2; Mean Time Post Injury=44.4mo. Intervention: Participants completed an individualized 12wk Specific Training Program (STP) combining aerobic dance, and slide and step training for 30min, 3x/wk compared to traditional muscular training (TMT) for 60min, 2x/wk for 12wk. Outcome Measure: Clinical Test for Sensory Interaction in Balance (CTSIB), Jumping Jack movement.</p>	<ol style="list-style-type: none"> Over time, all of the participants' performance of the exercises improved. The analysis of balance revealed a significant difference between pre- and post-training sway area for the STP group (p<0.05) but not for the TMT group.
<p>Gurr and Moffat (2001) UK Pre-Post N=41</p>	<p>Population: TBI; Mean Age=44.1yr; Gender: Male=28, Female=41; Mean Time Post Injury=78.7mo. Intervention: Therapy consisted of a behavioral exposure program to movements and activities that provoked vertigo and anxiety in order to assist compensation of vestibular dysfunction and habituation to physical anxiety symptoms. Outcome Measure: Vertigo Symptom Scale (VSS), Vertigo Rating scale (VRS), Vertigo Handicap Questionnaire (VHQ), Sway-Monitor Assessment.</p>	<ol style="list-style-type: none"> At the end of therapy, participants' vertigo symptoms and somatic anxiety had significantly decreased from pre-test to post-test (both p<0.01). Significant reductions in VRS scores were shown from pre-test to post-test, and post-test to follow up (both p<0.01). Patients were able to perform exercises significantly faster (p<0.01) and with significant lower rating of dizziness (p<0.01) after the intervention. Post-test levels of postural sway on the sway monitor (ability to balance on an unstable surface with eyes open) had significantly improved compared to pre-test levels (p=0.008). Vertigo handicap levels (VHQ scores) significantly decreased from pre to post intervention (p<0.01).

Discussion

Patients with TBI suffering from BPPV should be specifically treated with repositioning maneuvers until complete resolution (Motin et al., 2005). Vestibular rehabilitation, alone or in combination with pharmacological treatment (i.e., betahistine dihydrochloride), as a treatment for balance disorders post TBI has been shown to significantly reduce recovery time when compared to pharmacological management alone (Naguib & Madian, 2014).

In a small sample of adults, aerobic dancing and slide-and-step training improved balance and coordination in patients many years following TBI, suggesting that long-term improvement of vestibular dysfunction is possible with the appropriate program (Dault & Dugas, 2002). Further, Gurr and Moffat (2001) added a cognitive aspect to vestibular rehabilitation. The authors attempted to restructure the maladaptive thoughts and belief patterns associated with the symptoms of provoked vertigo. This multidimensional psychological approach was effective in improving vertigo symptoms, independence, emotional distress, physical flexibility and postural stability (Gurr & Moffat, 2001).

In terms of more familiar therapy interventions for balance, one study compared standard physiotherapy and standard therapy in addition to a home-based rehabilitation program (Peirone et al., 2014). Both groups showed significant improvements on the Goal Attainment Scaling and the Balance Evaluation System Test. However, when comparing these interventions, those receiving home-based rehabilitation made significantly greater improvements on the Balance Evaluation System Test (Peirone et al., 2014). Despite these findings, this study was underpowered and further investigation is needed before definitive conclusions are made.

Conclusions

There is level 4 evidence (from one pre-post test; Gurr & Moffat, 2001) that vestibular rehabilitation programs, such as a behavioural exposure program, may improve symptoms of vertigo in patients after TBI.

There is level 2 evidence (from one randomized controlled trial; Naguib & Madian, 2014) that vestibular rehabilitation programs, alone or in combination with betahistine dihydrochloride, can improve recovery time for balance disorders in individuals with an ABI compared to betahistine dihydrochloride alone.

There is level 2 evidence (from one prospective controlled trial; Dault & Duga, 2002) that using a combined aerobic dancing and slide and step training program may reduce balance and coordination deficits post TBI.

There is level 1b evidence (from one randomized controlled trial; Peirone et al., 2014) that an individualized dual-task home-based rehabilitation programme may improve balance control in individuals with ABI.

There is level 4 evidence (from one post-test; Motin et al., 2005) that the Particle Repositioning Maneuver may lead to improvements in Positional Nystagmus in individuals with severe TBI.



KEY POINTS

- Combined aerobic dance and slide and step programs may improve balance and coordination post TBI.
- A vestibular rehabilitation program may improve symptoms of vertigo in patients following TBI.
- Vestibular rehabilitation programs, alone or in combination with betahistine dihydrochloride, can improve recovery time for balance disorders in individuals with an ABI.
- An individualized dual-task home-based rehabilitation programme may improve balance control in individuals with ABI.

Olfactory Dysfunction

Posttraumatic olfactory dysfunction following TBI is caused through underlying mechanisms including damage to the olfactory nerve fibers as they cross the cribriform plate, injury to the sinonasal tract, and hemorrhage within the olfactory cortex (Whitcroft & Hummel, 2019). Impairments in olfactory function can be quantitative (reduced or lack of ability to detect and perceive odors) and/or qualitative (distortion in quality of odor stimuli). Based on their severity, quantitative olfactory impairments can be further divided into *hyposmia* (reduced olfactory function) and *functional anosmia* (inability to detect odors) (Bratt et al., 2020; Limphaibool et al., 2020). The presence of olfactory dysfunction post TBI hinders quality of life in affected individuals and often leads to heightened risks of personal injury. Although TBI is one of the main causes of olfactory dysfunction (Limphaibool et al., 2020), the management of olfactory dysfunction in the TBI population has been largely neglected in current research and clinical practice.

Previous human research and animal trials have demonstrated the benefits of various pharmacological options for olfactory dysfunction interventions, such as intranasal insulin, minocycline, zinc gluconate, vitamin A, and corticosteroids (Whitcroft & Hummel, 2019). Olfactory training has also shown to be effective in improving olfactory function (Sorokowska et al., 2017). To date, one study has examined the effectiveness of corticosteroids and olfactory training in treating olfactory dysfunction in patients with TBI (Table 24).

TABLE 24 | Interventions for the Treatment of Olfactory Dysfunction Post ABI

Author, Year Country Study Design Sample Size	Methods	Outcome
<p>Bratt et al. (2020) Norway Pre-Post N_{Initial}=23, N_{Final}=22</p>	<p>Population: TBI=23; Mean Age=49±13yr; Gender: Male=17, Female=6; Mean Time Post Injury=62±25mo; Severity: Mean GCS=9±3. Intervention: Participants with posttraumatic olfactory dysfunction following TBI were treated with oral corticosteroids (30mg prednisone, once daily) for 10d, followed by olfactory training, twice daily for 3mo. Outcome measures were assessed at baseline, the end of corticosteroid treatment, olfactory training and after 12mo. Outcome Measures: Olfaction (mean threshold, discrimination, and identification score (TDI)).</p>	<ol style="list-style-type: none"> 1. The TDI significantly improved from baseline to follow-up (14.4±7.3 versus 20.8±7.7, p<.001). 2. Half of the participants experienced clinically significant improvement of >5 TDI points. 3. Improvement was not associated with any sociodemographic, trauma-related characteristics or olfactory function at baseline.

Discussion

In a recent study by Bratt et al. (2020), participants with posttraumatic olfactory dysfunction post TBI received sequential treatment of oral corticosteroids (30mg prednisone, once daily for 10 days) and olfactory training (twice daily for 3mo). At 12-month post-intervention, participants demonstrated a significant improvement in olfaction from baseline (Bratt et al., 2020). With limited research on interventions for olfactory dysfunctions following TBI, any conclusions regarding the effectiveness of corticosteroids and olfactory training in the TBI population should be drawn with caution.

Conclusion

There is level 4 evidence (from one pre-post test; Bratt et al., 2020) that corticosteroids and olfactory training may improve olfactory dysfunction in individuals with moderate to severe TBI.



KEY POINTS

- Corticosteroids and olfactory training may improve olfactory dysfunction in individuals with moderate to severe TBI.

Pain Post TBI

Pain is defined as “an unpleasant sensory and emotional experience associated with actual or potential tissue damage...” (p.210) (International Association for the Study of Pain, 1994); the relationship between pain and tissue damage is not constant or uniform. Pain following an injury or surgery can be either acute or chronic, and often lasts for months or years post injury. Acute pain is usually associated

with defined tissue damage or a pathological process, and although it usually occurs at the time of injury as a one-time event, it may reoccur as a series of time limited events (Gould, 2007). Chronic pain is usually defined as pain that continues for more than three to six months and is often not as well associated with tissue damage or a pathological process. Using a separate classification, pain can also be defined as subacute (pain between the end of the first month post injury and six months post injury) and recurrent acute (pain that persists over an extended period of time but recurs as isolated pain episodes).

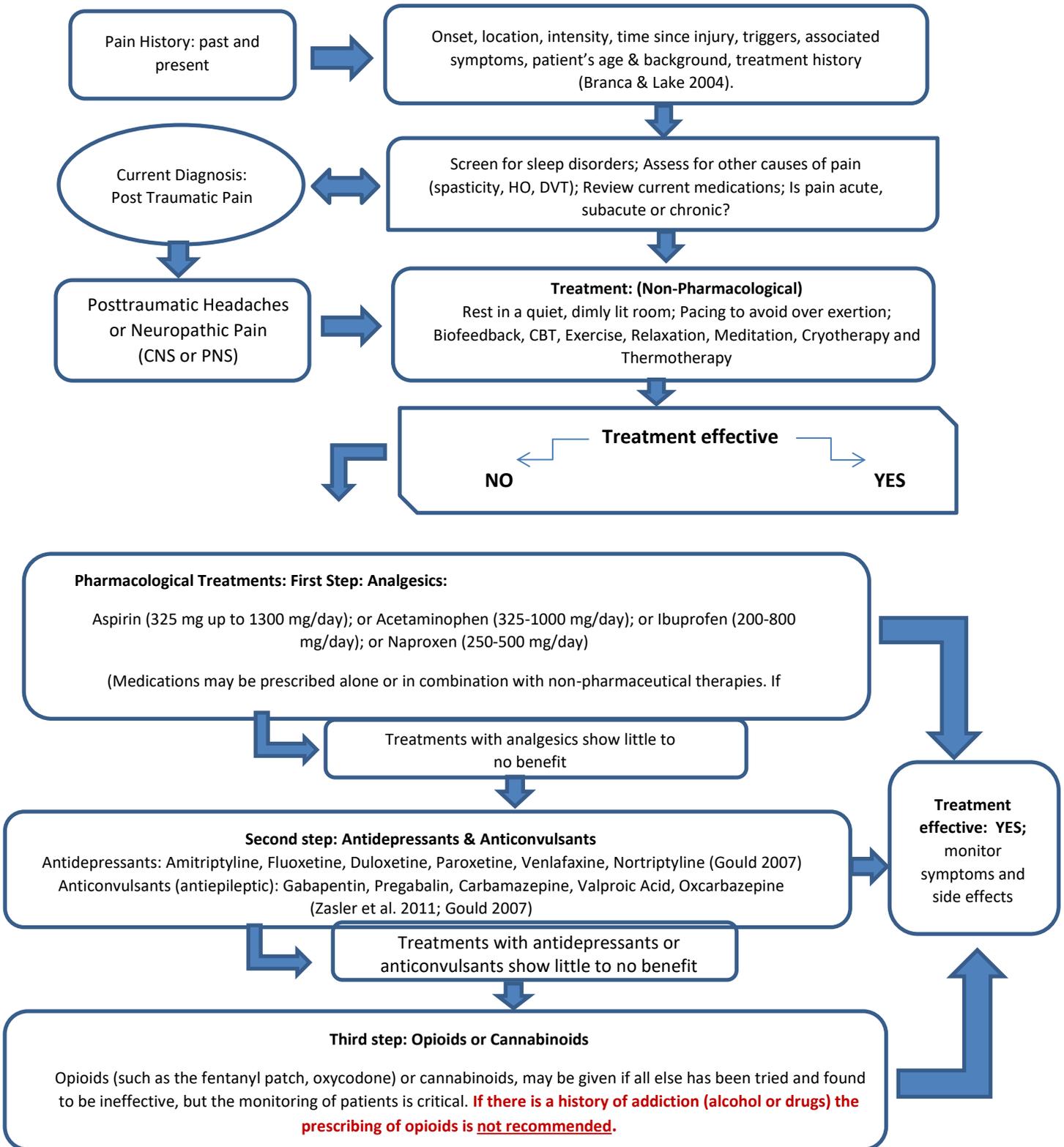
There has been very little information in the literature regarding the prevalence, etiology, assessment, and treatment of pain post TBI (Zasler et al., 2011). This may be the result of pain syndromes being overlooked in patients with a TBI for a number of reasons (Gellman et al., 1996). Multiple etiologies including orthopedic injuries, burns, organ injuries, or central or peripheral nervous system injuries can result in acute or chronic pain in those recovering from a TBI (Ivanhoe & Hartman, 2004). A lack of recognition or diagnosis of pain can lead to an increase in aggression and agitation, or an inability to participate or benefit from rehabilitation (Ivanhoe & Hartman, 2004; Sherman et al., 2006). In individuals who have sustained a moderate or severe TBI, the diagnosis of pain is often made through the combination of symptoms described by the patient and information provided by family members. Pain post TBI can evolve from episodic pain to daily pain with an increasing negative impact over time, as pain ultimately impacts participation in rehabilitation and thereby slows recovery (Branca & Lake, 2004).

Pain is believed to be more common immediately post injury (acute pain) and it is widely accepted that this pain will resolve as the damaged tissue recovers (Uomoto & Esselman, 1993). The focus is on management of symptoms over a relatively short defined period of time and on assisting the healing of damaged structures. Chronic pain by its very nature may not resolve, or is very slow to resolve, and often manifests itself as post traumatic headaches (PTH), neck and shoulder pain, back pain, peripheral nerve injury, heterotopic ossification, and pain related to spasticity (Hoffman et al., 2007; Lahz & Bryant, 1996; Ofek & Defrin, 2007). In a study conducted by Lahz and Bryant (1996), chronic pain was reported by 52% of those who were diagnosed with a moderate to severe TBI and 58% of those diagnosed with a mild TBI. Of those reporting pain, over 80% reported experiencing pain on a daily basis (Lahz & Bryant, 1996). Comparable rates were given by Hoffman et al. (2007) who examined a bodily pain scale one year post TBI. Of the 146 individuals who participated, 74% of participants reported experiencing pain and 55% of those reported that pain interfered with a variety of daily activities. Higher rates of pain were also related to gender, lower Functional Independence Measure scores, higher rates of depressive symptoms at baseline and again at one year post injury, and lower scores on the Community Integration Scale. Those who were injured in acts of violence reported experiencing greater pain (Hoffman et al., 2007). Pain is significantly associated with depression, with one study reporting rates of pain and depression as 70% and 31%, respectively and 34% and 22%, respectively at one year follow-up (Sullivan-Singh et al., 2014). Pain related to orthopedic injuries, spasticity, or heterotopic ossification will not be covered in this section. For a more detailed discussion on spasticity and treatments post ABI please see section 4.2.5 in this module and a detailed discussion on heterotopic ossification post ABI is available in Module 11. Due

to the complexities of pain, we have decided to focus on pain post TBI specifically. The diagnosis of pain post TBI is an important part of an individual's recovery.

Problems associated with pain include a delay in cognitive recovery, sleep disorders, fatigue, elevated levels of anxiety, depression, and post-traumatic stress disorder (Dobscha et al., 2009; Hoffman et al., 2007). Cognitive deficits associated with TBI may prevent individuals from using adaptive pain coping strategies that are critical to the management of chronic pain. When treating pain post TBI, it is important for clinicians to identify the causes of pain, not just the symptoms (Zasler et al., 2011). To reduce the impact on cognitive recovery, treatment plans should take into consideration the medications the patient is already receiving, as well as the location, type, and frequency of the pain. It should be acknowledged that in many cases the pain generator persists in which case pain can only be managed. Treatment for pain often involves an interdisciplinary approach (Branca & Lake, 2004). To increase the likelihood of compliance with treatments, a good working relationship between physicians and the patient is needed. Overall, more research is needed to assess the effectiveness and efficacy of these treatments in the TBI population. For a summary of these findings please see Figure 1.

Figure 1: Treatment for Sub-acute/Chronic Pain Post Traumatic Brain Injury



Assessing Pain Post TBI

Pain itself is both complex and subjective; thus, self-reports are vital to any treatment plan. Descriptive details related to the intensity, the length of time the pain is felt, the location, and what exacerbates or relieves the pain are vital in developing an individualized treatment strategy (Zasler et al., 2011). There are several tools and assessments used by physicians and therapists to assist in diagnosing and measuring pain. Amongst these is the numeric rating scale (NRS), the visual analogue scale (VAS), the Headache Diary, the Headache Disability Inventory, and the McGill Pain Questionnaire.

Visual Analog Scale

The Visual Analog Scale (VAS) is available at no cost and has been used with many adult populations to assess pain intensity. The scale is a horizontal or vertical line, usually 10 centimeters in length and is completed by the respondent. Two verbal descriptors, no pain and the worst pain imaginable, anchor the scale (Zasler et al., 2011). Generally, those completing the scale are asked to describe the pain within the past 24 hours. A ruler is used to the distance between the no pain anchor and the line that the respondent has drawn. Higher scores indicate greater pain (Hawker et al., 2011).

Numeric Rating Scale

The Numeric Rating Scale (NRS) is also commonly used to assess pain. Here the patient rates the pain they are experiencing on a scale of 0 to 10. The NRS, like the VAS, is anchored with no pain and the worst pain imaginable. Individuals are generally asked to report on pain intensity within the past 24 hours. This scale can be administered verbally or graphically. A higher score indicates higher levels of pain (Hawker et al., 2011). A 30% reduction on the NRS is clinically important and has been found to be equivalent to ratings of moderate relief or much improved (Farrar et al., 2001).

McGill Pain Questionnaire

The McGill pain questionnaire, designed for adults with chronic pain, measures the sensory, affective, and evaluative aspects of pain and pain intensity (Hawker et al., 2011). This paper and pencil questionnaire is administered by an interviewer with the respondent present. The respondent is asked questions and must select one word from a list presented to them which best describes their present pain. If the pain an individual is feeling cannot be described by the words presented to them, then no word is selected. Scores are based on the number of words selected with higher scores indicating greater levels of pain.

Headache Disability Inventory

The headache disability inventory was designed to measure the impact of headaches on activities of daily living (Jacobson et al., 1994). This self-report scale consists of 25 items designed to probe the functional and emotional impact of headaches in a patient's life. The scale has been found to be easy to complete - items are measured as either a yes or a no - and simple to score and interpret (Jacobson et al., 1994).

Headache Diary

Those who are asked to maintain a headache diary are required to log their headaches on a daily basis. Recorded in the diary is the time of day the headache begins, the intensity of the pain, any medication being taken, and any triggers for the headache. Additionally, individuals are asked to record alcohol consumed, periods of fasting, foods eaten, sleep patterns, weather, stress levels, emotional ups and downs, and for women, date of their menstrual cycle (Arnstein, 2004). A variety of headache diaries or headache calendars are available. These diaries potentially allow the patient to gain better control over their pain by identifying its potential causes, and provide feedback regarding treatment efficacy (Branca & Lake, 2004).

Pain Syndromes Post ABI

While the pain an individual with an ABI experience can vary, there are several defined pain syndromes that are common post ABI. Defining the pain someone experiences as a specific pain syndrome can be valuable in determining the ideal treatment method.

Neuropathic Pain

Neuropathic pain is initiated or caused by a primary lesion or by dysfunction of the nervous system (International Association for the Study of Pain, 1994). Peripheral nervous system pain can result from mechanical trauma, metabolic disease, neurotoxic chemicals, infection, or tumor (Costigan et al., 2009; O'Connor & Dworkin, 2009). On the other hand, central nervous system pain may be associated with spinal cord injury, stroke, TBI or multiple sclerosis (Costigan et al., 2009). Neuropathic pain can result from compression of peripheral nerves when patients are immobilized for long periods of time and diagnosis is often based on careful medical evaluation (careful history, physical and neurological exams, MRI findings, blood, and serologic tests) (Dworkin et al., 2003).

Despite clear diagnostic guidelines, treatment remains a challenge, as even effective treatments offer only partial pain relief (Finnerup et al., 2005). Common interventions for the treatment of neuropathic pain include pharmacological agents, such as: amitriptyline, pregabalin, gabapentin, duloxetine, carbamazepine, lidocaine, and opioids (Waszkielewicz et al., 2011). When considering treatments, it is important to keep in mind the safety and efficacy of these drugs; particularly how they interact with other medications and how they will impact neurological recovery post TBI. More specific information on interventions for neuropathic pain are discussed in anticonvulsant and cannabinoids section.

Central Pain Syndromes

Zaslar et al. (2012) have defined central pain as “pain associated with lesions of the central nervous system” (p 967). Treatments are limited in number and efficacy (Nicholson, 2004), however, the goal is often a reduction in pain and not complete relief. For example, studies have examined the effects of lidocaine and IV morphine in alleviating central pain syndromes, but the results have been mixed (Attal et al., 2000; Attal et al., 2002).

Post Traumatic Headaches

Damage to the skull, brain tissue, or cervical spine can result in PTHs that can be serious and incapacitating (Watanabe et al., 2012). According to Elkind (1989), a headache is a common and dominant symptom of TBI, with approximately 44% of those who sustain a closed head injury developing PTHs. Head, neck, and shoulder pain usually begins within the first 24 to 48 hours post injury, however PTH may appear immediately after the injury and subside, or occur days, weeks or months following the injury (Young, 2001). Factors that may lead to PTHs include chronic muscle contraction, chronic and diffuse muscle strain, and anxiety (Hillier et al., 1997). Visual or vestibular system complications may also result in headache syndromes. Studies have found that a PTH often resolves itself within the first 6 to 12 months of injury; however, in 18-33% of the TBI population headaches persist longer than one year (Lew et al., 2006; Seifert & Evans, 2010). Estimating the number of individuals who develop PTH is difficult as there is lack of consistency in how PTH is defined which may reflect limited understanding of its pathophysiology.

Previously, studies looking at the incidence of PTH reported that those who sustained a mild TBI were more likely to report problems with headaches than those who sustained moderate to severe TBIs (Couch & Bearss, 2001; Gurr & Coetzer, 2005; Uomoto & Esselman, 1993). However, more recent studies have found that individuals with moderate or severe TBIs report experiencing headaches even at one year post TBI (Hoffman et al., 2011; Hoffman et al., 2007; Lainez & Pesquera, 2011). In a survey of 485 individuals, Hoffman and colleagues (2011) found the prevalence of headaches during the first year of recovery post TBI was 40%, regardless of the severity of injury. Lucas (2011) found that almost 60% of respondents who reported experiencing headaches, also reported experiencing migraines or probable migraines. Other headaches reported were tension type headaches, cervicogenic headaches, or unclassifiable headaches. Despite what is known about PTH, there remains a need for further epidemiological, clinical, and pathophysiological studies (Lainez & Pesquera, 2011). Studies evaluating interventions for post traumatic headache can be found in the following sections: Biofeedback to Manage Post Traumatic Headache, Cognitive Behavioural Theory, Manual Therapy, and Cryotherapy and Thermotherapy.

Non-Pharmacological Interventions for Pain and Post Traumatic Headache

Early detection and treatment of pain is regarded as crucial to reduce its impact and help individuals develop appropriate approaches to dealing with their pain (Ivanhoe & Parrilla, 2002). As mentioned previously, deciding on a treatment for both general pain and PTHs may be challenging due to the many underlying factors of TBI and the fact that some pain conditions are only partially responsive to treatment. Given that pharmacological interventions may worsen cognitive deficits post TBI, non-pharmacological interventions should be incorporated into the treatment plan.

Non-pharmacological interventions for both chronic pain and PTH may include: biofeedback, cold and heat packs, massage therapy, acupuncture, and exercise (Medina, 1992). Biofeedback, relaxation, meditation, and CBT are considered the gold standard of behavioural treatments for pain (Branca & Lake, 2004). In a review of manual treatments for migraines, massage therapy, physiotherapy, relaxation, and chiropractic spinal manipulative therapy were found to be just as effective as propranolol and topiramate at reducing symptoms (Cassidy et al., 2014). Physiotherapy exercises have also been suggested to treat pain; however, unless the pain is controlled, caution is recommended when using these exercises to prevent aggravating the painful structures further (Medina, 1992). Lifestyle changes are also suggested to prevent the onset of PTH, such as getting enough sleep and daily exercise.

Biofeedback to Manage Post Traumatic Headache

According to a study by Mullally et al. (2009), biofeedback therapy does not significantly reduce the number and severity of headaches in individuals who were diagnosed with migraines or tension type headaches. However, several earlier studies found more positive results. A study by Ham and Packard (1996) studied 40 individuals who sustained a mild TBI and were experiencing post traumatic headaches. Participants participated in biofeedback sessions and were placed on anti-depressants and anti-inflammatory or non-narcotic analgesics. Participants began treatment on average 12.7 months post injury, although in half of the participants PTHs occurred immediately post injury. Biofeedback was reported to help 93% of participants to some degree with those who waited longer to begin biofeedback therapy found it less successful. Individuals who had more sessions and began treatment sooner found the sessions to be very beneficial. Unfortunately, the research on this topic for the moderate to severe TBI population is limited.

TABLE 25 | Biofeedback and Post Traumatic Headache

Author, Year Country Study Design Sample Size	Methods	Outcome
<p>Tatrow et al. (2003) USA Cohort N=14</p>	<p>Population: TBI; Mean Age=43yr; Gender: Male=2, Female=12; Mean Time Post Injury=50mo. Interventions: Participants participated in a two-phase treatment program. Phase one was thermal Biofeedback and Progressive Muscle Relaxation (PMR) for those with migraine type headaches. For those with tension headaches EMG biofeedback and PMR were given. This phase was completed by half the group (n=7) and lasted 12 sessions (2/wk). The other participants were wait-listed. Phase two was not related to post-traumatic headache and is not reported here. Outcome Measure: Headache Index Score and Post-concussion Syndrome Checklist.</p>	<ol style="list-style-type: none"> In 90.4% of sessions participants decreased muscle tension and 87.6% of the time participants receiving thermal biofeedback increased temperature. 4 of 14 participants had a clinically significant improvement in headache activity. 6 participants showed some improvement in terms of headaches, 2 minor improvements and 2 worsened. Scores on the Post-concussion syndrome checklist decreased from pre to post treatment (p<0.05) for the treatment group.

Discussion

In the study by Tatrow et al. (2003) PTH were targeted for six weeks in 14 individuals. The first four sessions consisted of progressive muscle relaxation, with biofeedback (Thermal and EMG) being introduced in the fifth session. As a result of the sessions participants learned to relax and control muscle tension. Relaxation ratings were on average 8.6 out of 10. Improvements in PTH were shown for the majority of participants. The treatment also lowered post-concussion syndrome checklist scores significantly in the treatment group (Tatrow et al., 2003).

Conclusions

There is Level 2 evidence (from one cohort study; Tatrow et al., 2003) that biofeedback is effective in the treatment of post-traumatic headaches; although, the severity of the participants was not clearly stated.



KEY POINTS

- Despite the positive results of the study investigating biofeedback and post traumatic headaches, further research needs to be completed using larger groups and only with those who have moderate and severe TBIs.

Cognitive Behavioural Therapy

Cognitive behavioural therapy (CBT) has been used to assist individuals in managing their pain. It is considered a diverse set of problem-specific interventions and incorporates physical, psychological, and behavioural approaches to managing pain (Roth & Pilling, 2008). With CBT the individual is taught to use self-regulation and self-control, and to take responsibility for one’s lifestyle (Martelli, 2012). This therapy has been used to help patients cope with the pain, depression, and anxiety associated with chronic headaches (Gurr & Coetzer, 2005; Wetherell et al., 2011). Despite the extensive use of CBT, there are not many studies evaluating its efficacy in treating pain post ABI (Table 26).

TABLE 26 | Cognitive Behavioural Therapy for Pain Management Post ABI

Author, Year Country Study Design Sample Size	Methods	Outcome
Gurr and Coetzer (2005) UK Pre-Post N _{initial} =41, N _{Final} =20	Population: TBI; Mean Age=44.05yr; Gender: Male=28, Female=13; Mean Time Post Injury=78.7mo. Intervention: The CBT program consisted of 3 weekly relaxation group sessions, which were followed by six 30min individual therapy sessions. Psychological intervention included: progressive muscle relaxation-combined with the use of imagery, psycho-education tailored to the individual, cognitive behavioural	<ol style="list-style-type: none"> 1. Twenty-four participants had tension-type headaches, 7 migraines, 4 had both previous types, 3 had tension-type and soft tissue/scar pain, and 3 had other types. 2. Headaches occurred a mean 14d per month and the mean length was 10.46hr. 3. Following the intervention, headache intensity (CPI) and frequency decreased significantly (p=0.004).

	<p>strategies, lifestyle management, and maintenance and relapse. Outcome Measure: Structured Diagnostic Interview, Headache Disability Inventory, Headache Needs Assessment (HANA), Nottingham Health Profile (NHP), Chronic Pain Index (CPI).</p>	<ol style="list-style-type: none"> 4. Headache disability, according to results on the HDI and HANA, were significantly reduced ($p=0.001$ and $p=0.02$ respectively). 5. According to the NHP, pain was reduced but this was not significant. 6. Emotional well-being as measured by the HDI-emotion and the NHP-emotion subscales was also significantly improved ($p<0.05$).
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Discussion

Gurr and Coetzer (2005) studied twenty participants who had sustained a mild to severe TBI and who had completed a CBT program for PTH. The CBT program consisted of progressive muscle relations, psychoeducation, cognitive behavioral strategies, lifestyle management and maintenance, and relapse prevention. After the intervention, headache intensity and frequency, and disability significantly decreased, while emotional wellbeing increased. Results from the Nottingham Health Profile pain scale found no significant differences in pain pre and post intervention.

Conclusions

There is level 4 evidence (from one pre-post test; Gurr & Coetzer, 2005) that cognitive behavioural therapy may improve post traumatic headache intensity and frequency but not pain, in those who have sustained a mild to severe TBI.



KEY POINTS

- **Cognitive behavioural therapy may be useful in managing post-traumatic headaches; however, may not be useful for headache-associated pain.**

Relaxation Training

Relaxation training, or progressive muscle relaxation, is a possible treatment for chronic pain and PTHs. Individuals are taught how to breathe from the diaphragm and how to tense and relax various muscles. Through such techniques, the muscle tension triggers associated with headaches can be better controlled (Arnstein, 2004). Over time, patients may be able to reduce the number of headaches or prevent the pain from worsening.

Manual Therapy

Manual therapy refers to more hands-on types of therapy such as massage therapy, traction, mobilization, and physical therapy. The purpose of these therapies is to reduce muscle tension, increase muscle length, enhance circulation, and increase mobility in the joints (Gould, 2007). The results from an earlier study indicated that manual therapy was more effective than cold packs in reducing pain associated with PTHs (Jensen et al., 1990).

Massage therapy involves either deep tissue massage or a lighter massage technique. Massage therapy has been shown to increase oxygenation and blood flow to the muscles being treated as well as to reduce pain (D'Arcy, 2011). Physical therapy involves the patients and a physical therapist working together to identify the areas where pain is being experienced. Therapy may involve stretching and or strengthening exercises, ultrasound to the affected areas, or the application of hot and cold packs. Physical therapy for both pain and chronic daily headaches focuses on the upper body, including the upper back, neck, and face (Sherman et al., 2006).

In an earlier study, Medina (1992) investigated the treatment of PTHs in 20 patients post TBI or spinal cord injury through individualized therapeutic sessions each lasting 30 minutes. Patients received educational sessions, biofeedback training, electromyographic biofeedback, or physical therapy sessions, and were placed on appropriate medication to treat the pain. The combination therapies were effective as 17 patients were able to return to work and 19 patients reported a decrease in PTH intensity.

Acupuncture

Acupuncture, one of the oldest forms of physical therapies, is a non-medicinal intervention involving a certified acupuncturist selecting specific points on the body to insert acupuncture needles. The points of insertion differ in every individual. Although research indicates that there is some benefit to acupuncture therapy, there is a lack of strong evidence supporting its effectiveness with the TBI population (Gould, 2007; Wong et al., 2012).

Cryotherapy and Thermotherapy

Heating and cooling therapy can provide relief to patients with TBI who suffer chronic headaches and neck pain (Table 27). Specifically, cryotherapy involves the application of cold to relieve pain while thermotherapy involves the application of heat to relieve pain (Pangarkar & Lee, 2011). Both therapies are typically used in conjunction with other treatments.

TABLE 27 | Cold Therapy for Pain Management Post ABI

Author, Year Country Study Design Sample Size	Methods	Outcome
<p>Jensen et al. (1990) Denmark RCT PEDro=4 N=19</p>	<p>Population: TBI; Mean Age=31.6yr; Gender: Male=7, Female=12; Mean Time Post Injury=359d. Intervention: Patients were randomized to one of two groups: the manual therapy group (n=10) or the cold pack group (n=9). Those in the manual therapy group received soft passive movements of the joint at the outer range of motion. Cold pack therapy involved placing the cold pack under the neck and shoulders of the individual. Each intervention period lasted 15</p>	<ol style="list-style-type: none"> 1. The pain index of those in the manual therapy group declined after the two treatments while remaining relatively constant in the cold pack group. 2. The manual therapy group reported the greatest reduction in pain at week 5. 3. Reduction in pain was significantly different (p<0.05) between the two groups at 5wk, with the manual therapy group reporting significantly less pain than the cold pack group. 4. Pain reduction for the manual therapy group decreased by 84% at 6wk.

to 20min. Interventions were given over a 12wk period.
Outcome Measure: Pain Schedules, Intensity of Headache on Visual Analogue Scale.

Discussion

Jensen et al. (1990) compared manual therapy to cold pack therapy for the treatment of PTH pain in 19 participants with head injury. Those in the manual therapy group reported a significantly greater reduction in pain following the intervention when compared to the cold pack group. The pain index for all participants was also correlated with the frequency of associated symptoms (dizziness, visual disturbances, and ear symptoms) and the use of analgesics.

Conclusions

There is level 2 evidence (from one randomized controlled trial; Jensen et al., 1990) that cold therapy may not be as effective as manual therapy for reducing post traumatic headache pain in individuals post ABI.



KEY POINTS

- Cold therapy is likely not as effective as manual therapy at reducing post traumatic headache pain in patients post TBI.

Yoga and Mindfulness

Similar to the principles behind cognitive behavioral therapy, and relaxation training, yoga and mindfulness is also thought to potentially reduce pain in individuals post ABI. In addition to its effects on pain, yoga and mindfulness is also thought to positively impact other areas of rehabilitation such as mood.

TABLE 28 | Yoga and Mindfulness for the Treatment of Pain Following an ABI.

Author, Year Country Study Design Sample Size	Methods	Outcome
Combs et al. (2018) United States Pre-post N _{initial} =29 N _{Final} =19	<p>Population: Mean age=32.8yr; Gender: Male=89.5%, Female=10.5%; TBI severity: Mild=3, Severe=12, Other=4, Unknown=10.</p> <p>Intervention: Individuals attended weekly group sessions for yoga, meditation, and mindfulness. There were 32 sessions in total, each lasting 60mins, where participants could attend as many or as few sessions as they would like.</p> <p>Outcome Measures: Overall health, physical health, experiencing pain, sleep benefits,</p>	<ol style="list-style-type: none"> 1. Correlational analyses revealed that participants believed that the potential benefits of the intervention increased with the number of groups attended for areas of overall health (p<0.001), physical health (p<0.05), mood and anxiety (p<0.001), focus and attention (p<0.05), and self-awareness (p<0.05). 2. The number of sessions attended was significantly correlated to predicting length of stay for overall health and mood (p<0.05).

mood, and anxiety, focus and attention, self-awareness. All measures were self-reporting questionnaires.

Discussion

A single pre-post study has examined the effects of yoga and mindfulness on pain in individuals with an ABI. Combs et al. (2018) found that individuals self-reported improvements in overall health and a reduction in pain correlated to the number of sessions they attended. Further research is needed to determine the extent of the benefits that mindfulness and yoga have to offer in the course of pain management following an ABI, however preliminary research is positive.

Conclusions

There is level 4 evidence (from one pre-post test; Combs et al., 2018) that the number of mindfulness and yoga sessions attended is positively correlated with a perceived reduction in pain and an increase in overall health.



KEY POINTS

- **Yoga and mindfulness may improve perceived pain and positively impact quality of life overall.**

Pharmacological Management of Pain and Post Traumatic Headache

There are a variety of medications used in the treatment of chronic pain post ABI and PTH. Aspirin or aspirin compounds, acetaminophen, and ibuprofen are often the first lines of treatment prescribed for chronic pain; however, adjuvant medications such as anticonvulsants, antidepressants, benzodiazepines, bisphosphonates, local anesthetics, antispasmodic agents, and topical agents may also be prescribed (Gould, 2007; Khan et al., 2011). In some cases, the prescription of opioids may be considered.

Anticonvulsants

The administration of anticonvulsants to treat pain post brain injury has been a common practice since the 1960's. It is thought that epilepsy and pain share a common pathogenesis, thus allowing anticonvulsant medications to be used in pain management, particularly neuropathic pain that is either peripheral or central in origin (Dickinson et al., 2000; Zasler et al., 2011). It has also been noted that the use of anticonvulsant medication seems to produce fewer adverse events (Gould, 2007). Anticonvulsants used to treat pain include carbamazepine, oxcarbamazepine, lamotrigine, gabapentin, pregabalin, and topiramate, however, there are limited studies investigating their effectiveness either in isolation or in

combination with other medications. Table 29 summarizes several antiepileptic medications that are used to treat pain post ABI.

TABLE 29 | Antiepileptic Medications to Treat Pain Post TBI (Gould, 2007; Guay, 2003; Zasler et al., 2011)

Antiepileptic Medication	Typical Dose; Dose Range	Adverse Events (partial list)
Carbamazepine (Tegretol®)	200mg q 8hr; 100-1600mg/day	Drowsiness, bone marrow suppression, kidney stones
Valproic acid (Depakene®)	250mg q 8hr; 600-2400mg/day	Drowsiness, headache, sleepiness, agitation, mood swings, memory loss
Phenytoin (Dilantin®)	100mg q 8hr; 200-600mg/day	Double vision, imbalance, slurred speech
Gabapentine (Neurontin®)	600mg q 8hr; 200-3600mg/day	Drowsiness, dizziness
Clonazepam (Klonopin®)	0.5mg q 8 hr; 2-7mg/day	Drowsiness, disequilibrium, abnormal behavior
Oxcarbazepine (Tripeptal®)	300-600mg q 12hr; 150-1800mg/day	Drowsiness, lightheadedness, dizziness
Lamotrigine (Lamictal®)	50-100mg q 12hr; 50-200mg/day	Rash, fatigue, stomach upset
Topiramate	25mg q 12hr; 200-400mg/day	Ataxia, impaired concentration, confusion, dizziness, fatigue, speech disturbances, language problems.
Pregabalin (Lyrica®)	300-450mg/day; 150-600mg/day	Drowsiness, dizziness
Levetiracetam (Keppra®)	250-500mg q 12hr; 250-1500mg/day	Drowsiness, dizziness

Valporic Acid and Divalproex Sodium

Valporic acid and divalproex sodium are antiepileptic medications that have been used to reduce pain, however, there are no clinical trials demonstrating its efficacy post moderate to severe TBI. A retrospective study was identified that investigated the effectiveness of divalproex sodium on PTH in a mild TBI population (Packard, 2000). The dosing was individualized; however the starting dose was 250 mg per day and was increased by 250 mg as needed. Results showed that 60% of those on divalproex found mild to moderate improvement in chronic daily PTH. Further, 19 of 28 participants who had chronic daily headaches reported mild to moderate improvement. Additionally, six participants were headache free after a single month of treatment. The authors suggest that divalproex is effective as it works by activating the inhibitory neurotransmitter γ aminobutyric acid (GABA). The authors noted that although PTHs that persist for more than one year are considered permanent, it is still possible to treat them effectively, allowing the patient to increase their activity level and perhaps reduce their dependence on other analgesics.

Pregabalin and Gabapentin

Pregabalin and gabapentin work by blocking neuronal calcium channels and have become widely used for the treatment of neuropathic pain, in particular, peripheral neuropathic pain. Gabapentin requires a longer time to reach a therapeutic dose compared to pregabalin, which can provide a faster response to pain as it has 90% bioavailability. Furthermore, pregabalin does not appear to have a negative effect on other medications that an individual may be taking (D'Arcy, 2011; Vranken et al., 2011). Gabapentin has

been found to be very effective in the treatment of neuropathic pain in the elderly and is considered the first line of defense with this population (Guay, 2003). Again, despite these medications being administered to individuals post TBI, there is limited literature supporting their effectiveness in this population.

In a RCT by Vranken et al. (2008), the effects of pregabalin on pain in those with either an ABI or spinal cord injury were examined. The intervention group received a flexible dose of pregabalin, starting at 150 mg per day. If the pain relief was insufficient, the dose of pregabalin was increased to 300 mg, then 600 mg if needed. The control group received a placebo. Participants were administered the medication or placebo twice a day over the span of four weeks. Results indicate those in the pregabalin group reported a significant decrease in pain intensity, measured by a VAS, compared to the control group ($p < 0.010$). When using the Pain Disability Index, no significant between-group differences were noted at the end of the intervention. Of note, those in the pregabalin group reported few side effects, indicating that the medication was well tolerated (Vranken et al., 2008).

Carbamazepine and Oxcarbazepine

Carbamazepine was once considered the drug of first choice for treating neuropathic pain (Gould, 2007). Despite its success, there has been considerable concern regarding the adverse effects that many individuals experience while on the medication. If administering carbamazepine, the monitoring of such adverse events is strongly recommended (Backonja, 2003). Oxcarbazepine has been found to be effective in the treatment of neuropathic pain and has also been reported to have an improved side effect profile compared to carbamazepine (Nasreddine & Beydoun, 2007). In patients experiencing painful diabetic neuropathy, oxcarbazepine resulted in decreased VAS pain scores; however, changes were not always statistically significant. When administered to patients with the pain of trigeminal neuralgia, oxcarbazepine was found to be effective in reducing pain (Nasreddine & Beydoun, 2007).

Lamotrigine

Lamotrigine, a newer anticonvulsant medication, has also been found to aid in the treatment of neuropathic pain often associated with diabetic neuropathy, spinal cord injury pain, phantom limb pain, postoperative and traumatic neuropathic pain, and cancer related neuropathy (Ettinger & Argoff, 2007; Wiffen et al., 2011).

Topiramate

Topiramate has been found to be successful in treating migraine and cluster headaches (Ettinger & Argoff, 2007). Although topiramate is believed to be effective in treating pain, it has been noted that any preexisting cognitive impairments (language, attentions, cognitive functioning, or memory) due to the brain injury itself may be exacerbated by topiramate (Tang et al., 2007).

Antidepressants

Among the antidepressant medications available, tricyclic antidepressants are the most commonly used for the treatment of pain, in particular, neuropathic pain (Gironde et al., 2009; Gordon & Love, 2004; Guindon et al., 2007). Medications such as fluoxetine, sertraline, paroxetine, or citalopram work best at controlling pain when there is an underlying primary problem such as depression. Tricyclic antidepressants used to treat pain include amitriptyline, nortriptyline, desipramine, doxepin, and imipramine (Gould, 2007). However, the mechanism of action for these medications in the treatment of pain is not yet fully understood. There is no evidence to support the administration of antidepressants to treat pain or PTH; Table 30 summarizes several antidepressants that are used to treat pain post ABI.

TABLE 30 | Antidepressants to Treat Pain Post ABI (Gould, 2007; Zasler et al., 2011)

Medication	Typical Dose	Adverse Events
Capsaicin (Zostrix®, Axsain®)	0.025-0.075% 3-4 times daily	Burning, skin irritation
Lidocaine 5% (Lidoderm®)	1-4 patches 12 hours per day	Skin irritation

Opioids

The use of opioids to manage non-cancer pain has been on the rise for the past several decades (Martelli, 2012). It is believed that neuropathic pain can be relieved by the administration of opioids, provided a balance exists between the optimal dose and any unmanageable side-effects (DelleMijn, 1999). A decrease in libido, sedation, mental dullness, difficulties concentrating, and a higher risk for developing osteoporosis have been reported when taking opioids (Ersek et al., 2004; Haanpaa et al., 2010). The risk of exacerbating cognitive impairments of patients with TBI is one of the reasons for clinicians' hesitancy to administer opioids for pain management. Although opioid use within a TBI population has been discussed in the literature, few studies investigate its efficacy for reducing pain within this population. When opioids are administered it has been suggested to start with a low dose and titrate up (Gallagher et al., 2006). Unfortunately with narcotics there is no recommended therapeutic dose (Khan et al., 2011); although with musculoskeletal complaints it is recommended that the dose not exceed 120-200 mg/day morphine equivalent dose (Haanpaa et al., 2010). Moreover, with opioids, because the risk of physical dependency and addiction is problematic, patients should be screened for addiction and dependency risk factors. Psychological problems and a history of substance abuse are considered the two most common risk factors for opioid misuse and addiction.

Franceschi et al. (2008) administered oxycodone to a group of polytrauma patients, five of which had mild head injury, admitted to an emergency department suffering from acute pain. Main pain sites for the group were the chest, neck, lower back, leg, heel, pelvis, upper arm, and shoulder. Oxycodone (10 mg twice per day for three days given orally) was found to significantly reduce pain for 14 of the 15 patients. One patient required an increase in medication (20 mg twice per day) to achieve pain relief. Overall, the medication was well tolerated by patients with some reporting mild side effects (light headaches, constipation, and nausea) (Franceschi et al., 2008). Oxycodone has been found to be

successful in reducing pain; however, it remains unclear as to whether this medication would be effective and well tolerated in those who sustain a moderate or severe ABI.

Cannabinoids

Cannabis sativa has been used to treat pain for centuries. However the use of cannabis and its derivatives to treat pain had fallen out of favour in the mid 1940's to the mid 1990's, possibly due to the suspected risk of addiction, abuse, dependence, cognitive effects, and other adverse medical and psychiatric effects (Aggarwal, 2013; Greenwell, 2012). The utility of the medication is gaining increasing recognition as physicians and other health care professionals increase their knowledge regarding the efficacy and safety of cannabinoid based medications (Aggarwal, 2013). Cannabis is generally administered through either inhalation, ingestion, or topically, with the method of delivery determining the rate at which the drug begins to take effect. According to Aggarwal (2013), the use of cannabinoids can result in muscle relaxation, anti-inflammatory effects, and neuroprotection in ischemia and hypoxia. Cannabinoids are used to treat cancer pain, pain associated with multiple sclerosis, human immunodeficiency virus, fibromyalgia, and rheumatoid arthritis. Although many studies have looked at the benefits of using cannabinoids to treat chronic pain, the results of many of these studies were inconclusive (Greenwell, 2012).

A study by Ware et al. (2010) examined the effects of cannabis at different potencies (0%, 2.5%, 6% and 9.4%) in individuals with post-traumatic or postsurgical neuropathic pain. Pain intensity was found to be significantly lower on 9.4% tetrahydrocannabinol cannabis than on 0% tetrahydrocannabinol ($p=0.023$). Further, when 9.4% tetrahydrocannabinol cannabis was compared to taking a placebo, patients experienced more drowsiness and fewer periods of wakefulness. Results from Ware et al. (2010) suggest cannabis is effective in the treatment of neuropathic pain. Due to the addictive properties of this group, cannabinoids should only be administered if there is no history of alcohol or drug addiction. Once on these medications, monitoring of patients is paramount.

Conclusions

Overall, a wide variety of interventions exist for sensory and motor rehabilitation post ABI. For motor impairment specifically a variety of interventions such as splinting, constraint induced movement therapy, and exercise programs have been shown to be effective for the remediation of motor deficits post ABI.

More pharmacological based interventions exist for the treatment of spasticity in general, compared to other areas of motor rehabilitation. The spasticity studies presented here present multiple therapeutic options as well as compare their efficacy in ABI specific populations. It is important to keep in mind that some of the pharmacological interventions discussed have a longer history of investigation than others, such as botulinum toxin injections, while newer pharmacological interventions may want to be interpreted with more care.

Ultimately the appropriate interventions should be agreed upon by the care-team with what is in the best interest of the patient, as well as discussing realistic expectations for recovery.

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