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ORIGINAL RESEARCH

Clinician Perceptions of Robotic Exoskeletons for Locomotor Training After Spinal Cord Injury: A Qualitative Approach

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Abstract

Objective: To describe the experiences of clinicians who have used robotic exoskeletons in their practice and acquire information that can guide clinical decisions and training strategies related to robotic exoskeletons.

Design: Qualitative, online survey study, and 4 single-session focus groups followed by thematic analysis to define themes.

Setting: Focus groups were conducted at 3 regional rehabilitation hospitals and 1 Veteran's Administration (VA) Medical Center.

Participants: Clinicians (N=40) reported their demographic characteristics and clinical experience using robotic exoskeletons. Twenty-nine clinicians participated in focus groups at regional hospitals that use robotic exoskeletons, as well as 1 VA Medical Center.

Interventions: Not applicable.

Main Outcome Measure: Clinicians' preferences, experiences, training strategies, and clinical decisions on how robotic exoskeleton devices are used with Veterans and civilians with spinal cord injury.

Results: Clinicians had an average of 3 years of experience using exoskeletons in clinical and research settings. Major themes emerging from focus group discussions included appropriateness of patient goals, patient selection criteria, realistic patient expectations, patient and caregiver training for use of exoskeletons, perceived benefits, preferences regarding specific exoskeletons, and device limitations and therapy recommendations.

Conclusions: Clinicians identified benefits of exoskeleton use including decreased physical burden and fatigue while maximizing patient mobility, increased safety of clinicians and patients, and expanded device awareness and preferences. Suitability of exoskeletons for patients with various characteristics and managing expectations were concerns. Clinicians identified research opportunities as technology continues to advance toward safer, lighter, and hands-free devices.

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Persons living with spinal cord injury (SCI) experience a number of health consequences related to the loss of mobility.[1] Conventional locomotor or gait training is effective in improving walking, yet for many individuals with SCI, this training may not improve walking ability enough for safe community ambulation.[2] Clinicians must choose from a myriad of rehabilitation technologies and therapeutic strategies to provide locomotor training for individuals with SCI. Body weight–supported treadmill training and overground training can enhance locomotion and provide health benefits. Body weight–supported treadmill training and overground training are both widely used in clinical settings, but

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require overhead harnessing in many cases, 2 or more therapists to promote proper stepping dosage, correct kinematics, maintain posture and balance, and to manually assist trunk, hips, and legs during stepping. It is costly in both personnel and equipment.[3-5] In recent years, lower limb robotic exoskeletons have emerged as a potential overground locomotor training tool for individuals with neurologic conditions. They provide the intensity and dose matching standard of care, but also provide, loading and structured kinematics which multiple clinicians offer. Although they facilitate favorable health outcomes for users, they may reduce clinician effort during therapy.[4,6-9]

Various organizations and investigators synthesize scientific evidence and provide recommendations, which influence clinicians' perceptions about locomotor or gait training.[10-14] Their perceptions are also influenced by their practice setting, geographic location, training, and knowledge. The use of robotic exoskeletons allows overground locomotor training for individuals with SCI with varying degrees of impairments at an early stage of rehabilitation when traditional methods of locomotor training are difficult. Furthermore, these devices allow individuals with SCI to practice walking in the community, enhancing continuity of care.[4]

Although there is early evidence to support the health benefits of robotic locomotor exoskeleton use,[7,15-19] there is limited research on clinicians' perspectives regarding applications for exoskeleton use in locomotor training. This study aims to describe clinicians' preferences, clinical practices, training strategies, and clinical decisions on how robotic exoskeleton devices are used with veterans and civilians with SCI.

Clinician perceptions of robotic exoskeleton use

Advancements in clinical practice depend on a cyclic process where evidence is integrated into practice and where clinical experience informs the evidence.[20] For this reason, clinician perspectives related to benefits and limitations of rehabilitation technologies are important. Heinemann et al[21] examined therapists' experience using robotic exoskeletons for overground walking in focus groups. Therapists described their experiences, evaluations, and training strategies with robotic exoskeletons. Participants reported using exoskeletons primarily in outpatient and wellness settings, though 1 center used exoskeletons during inpatient rehabilitation. A typical outpatient episode consisted of 20-30 sessions and involved at least 2 staff members. Treatment goals included standing, stepping, and gait training. Benefits attributed to use of exoskeletons included physiological (reduced pain, improved bowel function), psychological, and social changes. Therapists noted the risk of falls, skin irritation, and high patient expectations. Hospitals used varied strategies for integrating robotic exoskeletons into therapy services.

Although the Heinemann study provides preliminary evidence to guide the integration of exoskeletons into rehabilitation services, a more detailed analysis of therapists' experience is needed to guide practice and to inform patient expectations. This study addresses 5 research questions: (1) How do clinicians evaluate appropriateness, patient characteristics, and realistic expectations regarding robotic locomotor exoskeleton therapy in rehabilitation and community settings? (2) What training strategies do clinicians use with patients and caregivers? (3) What benefits do clinicians perceive from using exoskeletons? (4) What preferences do clinicians have regarding which robotic exoskeleton they use? (5) What limitations to robotic locomotor exoskeletons do clinicians identify, and what hardware and software developments do clinicians recommend?

List of abbreviations:

SCI **spinal cord injury**
VA **Veteran's Administration**

Methods

Institutional review boards at collaborating organizations provided ethical approval. All participants provided informed consent and received an honorarium. The U.S. Army Medical Research and Development Command Office of Research Protections, Human Research Protection Office also approved the protocol.

Sample

Using a phenomenological approach, this study used quantitative and qualitative methods to address the aims by collecting survey data and conducting focus groups. Eligibility criteria were employment as a clinician or researcher with experience using robotic exoskeletons. A convenience sample of Veteran's Administration (VA) clinicians who worked at a designated ReWalk/Ekso/Indego Training Center and a convenience sample of clinicians at civilian settings who had experience delivering exoskeleton therapy were invited to participate. A moderator (A.W.H.) facilitated onsite focus groups at the rehabilitation hospitals and a videoconference focus group with the VA medical center between June and December 2018. Onsite focus groups were preferred, but we were only able to recruit VA clinicians to participate via videoconference. All focus groups followed the same procedures, used the same focus group guide and the same moderator. Analysis of both types of focus groups followed the same procedures.

Procedures

Clinicians completed preliminary surveys using the REDCap web application (REDCap Northwestern University, a REDCap Consortium member, NIH/NCATS Northwestern) to report demographic information and to report quantifiable details about their experience using robotic exoskeletons. All survey participants were invited to join the focus groups.

Researchers developed a focus group topic guide (supplemental appendix S1, available online only at http://www.archives-pmr.org/). The moderator (A.W.H.), an investigator with 40 years of experience in qualitative research projects, led the focus groups. A court reporter provided verbatim transcripts for content analysis. A research team member, uninvolved with coding the specific transcript, uploaded deidentified documents to a secure server, imported them into NVivo 12 Pro software,[a] and shared them with the team for coding. We used the Standards for Reporting Qualitative Research to guide the preparation of this article.[22]

Data analysis

We used a thematic approach to summarize clinician responses.[23,24] This approach involved open coding and interpreting interviews line-by-line; reading and annotating data; describing,

Table 1 Clinicians' demographic and robotic exoskeleton experience

Demographic Characteristics	Site A	Site B	Site C	Site D	All Sites
n	10	9	8	2	29
Mean age (y)	34	37	36	32	35
Age (y) (range)	26-44	32-47	30-45	30-34	26-47
SCI clinical experience (y) (mean)	5.8	9	8.6	6.5	7.6
SCI clinical experience (y) (range)	1-12	4-13	2-22	4-9	1-22
Exoskeleton experience (y) (mean)	3.7	3.9	4.1	3.5	3.0
Exoskeleton experience (y) (range)	1-11	2-6	2-7	2-5	1-11
Sex (%)					
Women	70	67	88	100	76
Race/ethnicity (%)					
White	90	100	88	100	93
Black	0	0	0	0	0
Asian/Indian	0	0	0	0	0
>1	0	0	13	0	3
Other	10	0	0	0	3
Declined to answer	0	0	0	0	0
Hispanic/Latinx (%)					
Yes	10	11	13	50	14
Exoskeleton experience type (%)					
Research	50	0	25	0	24
Clinical	0	66	50	100	38
Research and clinical	50	44	25	0	38

classifying, and interpreting data into codes and themes, and then representing and visualizing data by 3 research team members. We used an inductive analytical approach to produce the codebook based on open coding of the first focus group interview.[25] The research team reviewed the first coded transcript to assess interpretations, reconcile discrepancies among the 3 coders, discuss initial findings, and make modifications. Different teams of 3 researchers coded the remaining transcripts. Two primary coders coded independently and then reconciled differences. The third coder read the transcript independently and reconciled the 2 primary coders' themes. When kappa coefficients did not meet or exceed 0.80, the team of 3 met to review codes and modify them to reach consensus and ensure interrater reliability. Finally, the entire team met to review and harmonize codes across sites. Thematic saturation was met after the 4 focus group transcripts were analyzed.

We enhanced methodological rigor by using a standardized, semistructured moderator guide and having 1 moderator conduct all focus groups. We ensured investigator triangulation by having 3 investigators independently code transcripts before reconciling themes.

Results

Demographic characteristics of focus group participants

Table 1 reports demographic characteristics of focus group participants. On average, clinicians were in their 30s, predominantly women and white. Experience with SCI patients averaged 7.5 years, whereas experience with exoskeletons averaged 3 years. Participants had clinical and/or research experience.

Table 2 provides details of clinicians' robotic exoskeleton training. One-third to one-half of the clinicians had attained certification with at least 1 exoskeleton manufacturer. Most worked in outpatient settings and had robotic locomotor training experience with fewer than 20 patients.

Clinicians who reported more experience using robotic exoskeletons had greater comfort using the devices with a broader range of individuals than did clinicians with less experience.

Focus group themes and perceptions regarding robotic exoskeletons

Results are organized by questions that reflect the structure of the focus group guide and the analysis of focus group members' statements. Table 3 is organized to illustrate themes from inductive coding of transcripts along with representative quotes. The first column in table 3 lists the high-level themes, the second column lists the mid-level themes, and the third column lists subthemes. Shown in parentheses are the number of unique occurrence of themes when there were no subthemes, or unique occurrences of mid-level and subthemes. Figure 1 provides a graphical view of theme, mid-level theme, and subtheme frequencies, with font size reflecting relative frequency.

Question 1: clinical evaluation

Appropriateness of patient goals

Clinicians were concerned about appropriateness of exoskeleton use for certain patients. Appropriateness was based on inclusion-exclusion criteria specified by the device manufacturers, patient goals for using the device, time since injury, and type or level of injury.

"Well, I think that's so individual and you may have recommendations and they may totally disregard them because they just have this visualization of them utilizing an exoskeleton, but to the point of, you know, using it within the kitchen, if that's your only

Table 2 Clinicians' training, experience, and certifications

n	29
Years worked (mean ± SD)	7.8±4.0
Type of RT exoskeleton experience (%)	
Rehabilitation therapy	37
Research	27
Both	37
Currently work with RT exoskeleton (%)	
Yes	83
Years worked with RT exoskeleton (mean ± SD)	3.3±2.7
Number of patients worked with using RT exoskeleton (mean ± SD)	
Inpatient	7.0±11.0
Outpatient	17.0±14.0
Unknown	0
What type of RT exoskeleton devices do you use? (%)	
Ekso Bionics	60
ReWalk Robotics	47
Parker Hannifin Indego	70
Other	23
Unknown	0
Decline	0
RT exoskeleton certifications (%)	
Ekso Bionics	50
ReWalk Robotics	40
Parker Hannifin Indego	60
Other	13
Decline	3
Ekso Bionics certification level (%)	
Level 1 initial training	30
Level 2 advanced training	33
Other	0
Decline	0
ReWalk Robotics certification level (%)	
Basic training	37
Advanced training	23
Refresher (informal)	3
Other	0
Decline	0
Parker Hannifin Indego certification level (%)	
Indego specialist	53
Indego trainer—clinic	30
Indego trainer—personal	27
Other	7
Decline	0
Have any of your patients purchased an RT exoskeleton? (%)	
Yes	33
No	53
Unknown	10
Decline	3
How many patients have purchased an RT exoskeleton? (%)	
1	13
2	15
5	5
Decline	3
Do you provide physical therapy services to veterans with SCI? (%)	
Yes	58

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(*continued*)

Abbreviation: RT, robotic.

goal, wouldn't a standing wheelchair potentially be a better alternative for you? Or maybe not, you know, but that may be a lower tech, lower cost alternative for that one activity if that's your sole goal. I think it really depends."

Patient selection criteria

Clinicians identified characteristics of patients who would be successful using an exoskeleton, including motivation, general health, learning style, confidence, and body awareness.

"You need someone who has the interest and who has appropriate goals and we feel confident that the device can potentially deliver on those goals. The person has to be motivated to do what it is that we think they should do in the device to get the benefits."

In addition, clinicians identified patient characteristics that might hinder exoskeleton use, such as limited arm strength, unsuitable body type, or argumentative or noncompliant behaviors.

"If the person is argumentative just in a regular therapy session, you are not going to put those guys in a robot, because they need to be able to really listen, to understand the thresholds, and what to do, and how to meet the tunnels, and just – all of the technical stuff."

Realistic expectations of exoskeletons

Clinicians discussed the need for patients to have realistic expectations regarding the capabilities of robotic exoskeletons. Patients may see others in the device and expect similar outcomes or they may find the exoskeleton does not provide the function that they expected.

"We're explaining that to them very honestly and saying unfortunately we don't expect this to allow you to be able to walk, but it can have a lot of other benefits, including you may notice that you're able to control your trunk better. You may notice that you're able to transfer a little bit better because you can maybe bring yourself forward better and do more with your trunk. You can reach from sitting. Maybe help with ADLs. So we are trying to put forward those positives, like what they can benefit out of the device use. But try to like let them know that this is unfortunately not what you thinks about to happen. Because a lot of times they ask, "Is this going to help me walk?" And unfortunately, you have to kind of make sure that they understand that that's not the goal for them."

"I think one of the maybe barriers or things that we've had to consider just in general is because it's kind of such a high profile device, when patients see somebody else in it, you know, their automatic kind of response is, well, I want to get in it and I want to try, too. And coming from that post-acute standpoint where we kind of know what it actually takes to get one, what the actual requirements are to purchase one and how people are actually really using it, the folks that have purchased one, we, you know, have to kind of manage expectations a little bit."

Table 3 Representative quotes

High-Level Theme (Frequency)	Mid-Level Theme (Frequency)	Subtheme (Frequency)	Representative Quotes
Device characteristics (25)			With the ReWalk the big thing that we were looking at was can we make these people independent in their lives by using this device. So I think that that is probably the most benefit to using these devices. We can return people to walking who really previously didn't have the possibility of doing that in the community.
			Different devices that have the variable assist features, like the Indego has the Therapy Plus and the EKSO has ability to put things in FIX, use Free Limb, things like that. Each device has its different approach to allowing persons to utilize their own residual function. So each device probably will change the person's ability to recover function differently.
	Models (2)		ASIMO
		Ekso (50)	They do have like a lot of videos, but it's different whenever it's – you can explain that particular story yourself, you know, it's just different – Indego and Ekso their customer support is phenomenal I mean – they are both – like they have PTs – they have clinicians that are so helpful.
		Indego (54)	I really like that you can use Indego for rehab and for home use.
			Usually takes about 15 minutes, and you get someone in the Indego or – well, the Indego much quicker with less staff.
		ReWalk (50)	ReWalk I would never use for rehab, ever. I would never do one of those. It's just the mechanics is bad, I would never use that. And none of the PTs here use ReWalk for rehab, just to be clear.
		Other (9)	And then there's a few devices that we're starting to work with that are not FDA approved yet.
			I am working with—a little bit with Honda, and perhaps hopefully soon being able to use their ASIMO walking assisted device. Also, work with Keeogo and Tamale.
Environmental characteristics	Setting	Clinical (20)	As an inpatient therapist, I never considered utilizing a robot, because most of the stays are pretty short.
Patient benefits	Physical functioning	Mobility (19)	With the ReWalk, the big thing that we were looking at was can we make these people independent in their lives by using this device. So I think that that is probably the most benefit to using these devices. We can return people to walking who really previously didn't have the possibility of doing that in the community.

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Table 3 (*continued*)

High-Level Theme (Frequency)	Mid-Level Theme (Frequency)	Subtheme (Frequency)	Representative Quotes
			And so I think the – being able to walk overground with individuals who might not necessarily be able to do that without a significant amount of assistance I think is extremely valuable.
	Physical (24)		I think of all the other health benefits, too, that again it's not well documented at this point, but that's one thing that being upright and walking gives you bowel/bladder, spasticity, as people mentioned, a lot of different health benefits that you can't get another way I think is something to consider, especially with, you know, taking it home, like, that might be the biggest benefit to taking it home in the long term is just from a health and wellness perspective versus a functional perspective, at least where it is at this point.
Patient experience	Realistic expectations (62)		Whether they have true understanding about the capabilities of—the real capabilities of exoskeletons, what they can and what they cannot do, that is where a lot of the conversations really have to happen, not going and seeing these cool marketing spots online and not hearing these really emotional, impressive stories from patients who have utilized them online but getting to the nitty-gritty of, well, this is where you are and these are your goals and this is the reality for you.
			And he said, well, my workers' comp offered to buy me an exoskeleton or a standing outdoor wheelchair, and he's like, I like to go hunting. I picked the standing outdoor wheelchair. He's like, I'm not – you know, as cool as this thing is, he's like, this doesn't give me what I want as far as my life and the things that I want to be able to do. And so that was kind of like an aha, like this guy's been in it and does great and loves it, but he's like, I don't want that.
			There's a very fine line between encouraging someone and telling them why you're doing it and having them run off with oh I'm doing this because I'm going to walk. And it would be nice if every single person that we saw every day would have that opportunity, but not everybody does. So, it's you have to manage expectation, gently and sensitively.

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Table 3 (*continued*)

High-Level Theme (Frequency)	Mid-Level Theme (Frequency)	Subtheme (Frequency)	Representative Quotes
			We don't endorse any of the 3, but I will say that we've had some issues with veterans that they see – they see this device: Oh, I want to use this. And I see John Smith did this, and this guy did a marathon in this. And I have some personal conflict with a lot of the marketing that's involved with the exoskeletons, particularly ReWalk, I think that it's – it's a little unnerving when guys do these marathons, half marathons in these devices, and then they are hospitalized for 2 weeks from sores. So that doesn't make the media, that's not on You Tube, you know. So my person that's the motor – like the Marine that just totally got the device, we had to actually kind of put a little restraint on him because he would push it too far, right.
*Patient risks of exo*skeleton *use*	Physical (23)		EKSO but because of the way the harness is, a limitation is just the anatomy of females. So sometimes it's put a lot of pressure on certain areas.
			If someone has a Foley catheter, you want to make sure that you're not occluding it and making sure that everything is in the proper position when you're working with a patient.
			We're obviously always concerned about skin, so just doing thorough skin checks pre and post. And if anybody has any existing skin conditions then just evaluating if that's going to be an issue if that's an area that would contact anywhere the robotic is going to be contacting.
Recommendations	From therapists	To manufacturer (21)	Because right now I think it's three days we do a trial, a two- to three-day trial, then they purchase one, they come back for the training, and it's like is it really going to meet what their real goals are type things so maybe we should look at that as an even longer trial period.
			I think you have to be highly adjustable; people come in all shapes and sizes. I mean, you want most people to get the benefit out of it. Be able to change the same device but make it for that short person or a tall person, that kind of thing.
Service delivery	Dose (19)		We only limit them to 36 session, or 35 sessions of using the device in order to be able to be good enough to pass the criteria to take the device home.
	Goals	Clinical (19)	Kinesthetic awareness, proprioception, you know, just the idea of upper coordination of any movement related to gait, I've found it helpful with the people I've used it on upstairs in inpatients.

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Table 3 (*continued*)

High-Level Theme (Frequency)	Mid-Level Theme (Frequency)	Subtheme (Frequency)	Representative Quotes
			It's not just for endurance or just for spasticity management or just for the emotional component of being able to get up and go. I want the trunk control. I don't want to see a lot of compensatory strategies, I don't want them to be overusing their upper extremities. I'm trying to get, you know, as much weight bearing but with the right pattern.
	Purchasing (24)		And he just like a lot of other people in the private sector for home use they would say: I am going to wait for the next version. I'm going to wait until they these are more durable and cheaper. I feel bad for the Indego people. Like I feel bad for the exoskeleton. But that's real, that is reality.
	Selection criteria	Appropriateness (48)	1. We look for people who may or may not be appropriate based on the inclusion or the exclusion criteria for using any of the devices. And if they would benefit from it. If they have gait goals and what those goals might be. 2. It depends on the goals. What those patient goals are and the appropriateness of a patient for a device.
			Maybe somebody who doesn't qualify based on their level of injury so maybe they would be able to use it here but from a functional standpoint they're doing other things to address their spasticity or they don't have a caregiver that would be able to assist them with the device at home or their insurance is not going to cover the device and they don't have the funding but they just want to get in it because they think it may help them walk again so kind of managing that what does it really do, what are the long-term uses of it, what is it actually for, what does it not do, and so trying not to just necessarily open that up to everyone just because they see it and want to do it.
	Selection criteria	Diagnoses (30)	We've been getting a lot of incomplete tetraplegic patients recently, so a lot of those patients would benefit from a robotic device, but they might not necessarily have enough trunk to do the Indego and not enough trunk or upper extremity strength to do the ReWalk.
		Patient characteristics (35)	Their gait pattern looks good, they don't have a lot of range of motion deficits, their spasticity is under control, they have some core stability, they look beautiful – perfect posture, perfect pattern, you know – and they trained with it for so long they're so good at it and independent and safe and they have great body awareness and safety awareness, and the problem is that there's just.
			Motivator is the best one, motivation has to be there, they want to get better and to improve.

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Table 3 (*continued*)

High-Level Theme (Frequency)	Mid-Level Theme (Frequency)	Subtheme (Frequency)	Representative Quotes
Therapist experience	Benefits (28)		If a limiting factor in walking someone is the clinician's ability to continue to sustain the activity and not the ability of the patient to sustain the activity, then that's a huge limiting factor to the total volume that you can actually get in in a session so I think that's a great point because we can get a lot more steps in with a device that's going to help facilitate those steps than if we're manually manipulating every step.
			So that's also where inpatient, sometimes it's easier to get them into a robotic system than to have the necessary four people it would take to truly do a treadmill session.
	Limitations (19)		But the biggest barrier is probably wounds, if they already have wounds, and the weight limit is 220.
			But I think one limiting thing with EKSO is that we usually always have two therapists in case something bad happens, it's a little harder to get out.
Training	Caregiver (31)		That's a perfect person, but you also have to have the perfect support person.
			And so far the caregivers that our patient have chosen, like one of them was a son who, I don't know how old he was, adult son that learned the device to be his second person or a wife, um, they've all been super supportive and learned the devices right along with the patient, and come to sessions. So I think that's really facilitated their success as well.
			I mean, obviously they have to be physically capable of it.
	Patient (40)		And, oh, my goodness I had one person from North Carolina figure out that whole motor neuron thing, he figured out how to use the device, Level 2 training, meaning community mobility, not just in the home within the first 2 days, completely independent. He took it to a school. He took it to a funeral. We did everything imaginable. We were on a light rail, that's never been done on an exoskeleton. Like it was easier – like a true community ambulator in the device.
			So it's like trying to show them what the benefits are, because we sort of know as therapists how to guide them, but sometimes they're not really sure what they're going to get out of the trials. And so it's sort of enlightening to them to get up there and actually see it put into play.

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Table 3 (*continued*)

High-Level Theme (Frequency)	Mid-Level Theme (Frequency)	Subtheme (Frequency)	Representative Quotes
			So in addition to gait retraining, balance, we have some individuals that benefit, I think, purely – you guys correct me if I'm wrong, but benefit purely from a spasticity management standpoint so getting someone in the device and taking them through ranges of motion and helping them manage at least for a short period of time, you know, extensor tone or trunk spasticity so I think we've had a few cases where it's been helpful to get someone in the device as a tool to kind of get them a little more mobile prior to some other sessions, as well.

Question 2: training strategies

Patient training/caregiver training

Home or community use of an exoskeleton requires extensive training and availability of a support person, often times a family member. Therapists must ensure that patients can and will use the device safely. The support person must be physically able to assist and supportive.

"I think that is why there is such extensive training. You have to train them and check off they are going to use it safely. I mean – and beyond that it's them and that second person that they are doing it appropriately."

"(Caregivers) need to commit the time; they need to commit the time to learning the device and being trained on it, and then being able to commit the time to that individual to actually use it out in the community."

Question 3: clinicians' experience

Clinicians' experience—benefits

Clinicians identified potential benefits to therapists using robotic exoskeletons: fewer clinicians are needed during treatments and patients take more steps with less clinician effort.

". . . you get that ability with the robot, and…you don't need to have two therapists down there. . . . and so potentially you can decrease how much personnel is needed . . . when you determine who is going to be there for safety versus hands-on work."

Question 4: clinicians' preferences

Preferences regarding specific exoskeleton

Clinicians preferred certain devices for specific reasons. They perceived Ekso and Indego devices as useful for balance training and as having good customer support. Indego gives vibratory cues for posture and has fall mitigation algorithms. They perceived ReWalk to be durable.

"You can use Ekso and Indego for just balance training."

"Indego is awesome with its vibratory cues, so if a person is standing just like at the walker or crutches or kitchen sink, you know, at the sink in our gym, whatever we want to stand at. If they are leaning too far forward, they will get a vibration sensation. The same with backwards, leaning too far back."

"ReWalk is definitely the most durable of the three right now."

Question 5: clinicians' recommendations

Exoskeleton limitations and suggestions

Clinicians described limitations of exoskeleton use, such as fear of falling, slow walking speed, and inability to replace wheelchair use.

"I think my biggest fear is falls. Falls and not everybody – you know, people get themselves in it sometimes and don't realize that their ankle is twisted or, you know, that there's something messed up with the setup or the pattern."

"So let's be honest, the device is—regardless of the city you are in, is not fast enough to get through a street, a crosswalk in enough time."

Clinicians recommended that manufacturers focus on developing hands-free devices and making devices adjustable to more body shapes and sizes.

"Or like several people have alluded to, like the self-balancing so that you don't have any safety concerns or balance concerns, or you have more hands-free accessibility to do things within the community. That would be a nice feature without sacrificing the weight and the limited speeds that we already have."

Discussion

Therapists described their preferences, clinical practices, training strategies, and clinical decision making regarding robotic exoskeleton in VA and civilian settings. Use of exoskeletons was similar in VA and civilian sites, but the VA funded personal devices for patients who meet eligibility criteria. We obtained clinician perspectives on (1) appropriateness, patient characteristics, and realistic expectations regarding exoskeleton use; (2) training strategies for patients and caregivers; (3) clinician benefits of exoskeleton use; (4) brand preferences; and (5) device limitations.

Although there is evidence to suggest benefits of robotic exoskeleton use, there is limited research on the clinician's

Fig 1 Size of the words is representative of the frequencies of the codes. Larger words are correlated with higher frequencies. The color of the words does not reflect any specific meaning but is used to differentiate each word in the figure.

perspective regarding use of robotic exoskeletons in practice. Heinemann et al[21] reported therapist's perspective on treatment goals, benefits, and risks of exoskeleton therapy. Mortenson et al[26] also focused on therapists' experiences using these devices in practice. Three main themes of their qualitative study were (1) difficulty learning to use the exoskeleton; (2) challenge of incorporating exoskeletons into daily life; and (3) lack of *magic bullet* effect. Therapists thought that exoskeletons may reduce physical demands on therapists during rehabilitation, but that there are barriers to including exoskeletons in practice, such as calibration time, intensive training required to use an exoskeleton, the cost of the device, and patients' comfort and safety using the device. They also emphasized that therapists must manage patients' expectations related to the use of exoskeletons. Findings of our study support these observations and also illuminate the importance of understanding patients' purpose for using an exoskeleton and the setting in which patients intend to use an exoskeleton. Patients with the resources to pay for therapy or exercise using an exoskeleton in a clinical setting bring different expectations than those who want to purchase an exoskeleton for community use. Clinicians' assessments need to be comprehensive in terms of assessing patients' motivation for use, goals, intended settings, functional status, and financial and supportive resources. These considerations must align well to support robotic exoskeleton training.

Many patients who are interested in exoskeletons do not meet manufacturers' eligibility criteria regarding level of injury, upper extremity function, anthropometric characteristics, and joint range of motion. Clinicians make decisions regarding use of exoskeletons based on clinical judgment and experience. Clinicians also consider timing relative to the stage of rehabilitation. Early after SCI, individuals need to learn skills necessary to perform activities of daily living and to prevent development of secondary conditions. These priorities leave little time to try robotic exoskeletons during inpatient rehabilitation.

Beyond physical characteristics, clinicians must assess whether potential users have appropriate goals and motivation. Using the device to enhance real-world function is a primary goal of many potential users. Clinicians found that it was often necessary to refocus users' expectations about realistic daily activities that they could accomplish while wearing exoskeletons.

For candidates who meet requirements for exoskeleton use and demonstrate awareness of device limitations, clinicians cited the need for extensive training as another consideration. Clinicians must verify that users can safely accomplish mobility activities while minimizing fall risk. Caregiver availability and education are also imperative. Clinicians must ensure that the user and companion adhere to the training schedule and must customize training for each user and their environment.

Clinicians with more clinical experience were also more likely to choose robotic exoskeletons for locomotor or gait training. This is consistent with prior literature indicating that clinical decision making is largely guided by clinical and continuing professional development experiences of the therapist.[27] These clinicians used exoskeletons for specific impairments or to attain functional goals that were not currently attainable by standard of care. Thus, they preferred specific devices and described specific features they believed would be valuable in future models, including integrated electrical stimulation, more durable components, and sensory cues to warn of balance problems. Finally, clinicians recommended that devices be able to accommodate various body anthropometrics.

Clinical implications

As devices improve, clinicians will require training on new features. Limitations of current exoskeletons may be ameliorated as hardware and software technology improves. For example, devices may become lighter, incorporate softer materials, become able to climb stairs, make positional changes, and navigate ramps. As device sophistication

increases, more individuals may be eligible to use them and for a broader array of tasks. Currently, clinicians need to understand the technical features of these technologies to appropriately use them for impairments and functional goals of patients.

Research opportunities

Clinicians suggested numerous design features that would improve the usability of robotic exoskeletons. In addition to reducing weight, they recommended materials that reduce cost, components that are easy to replace, designs that allow easy donning and doffing, and self-balancing capabilities.

Study limitations

Readers should note that all participants worked at SCI Model System sites or a VA Medical Center, which makes them less representative of therapists working in settings with fewer SCI patients or with less experience using robotic locomotor exoskeletons. The study design does not allow us to describe geographic variations in exoskeleton experience.

Conclusions

Clinician focus groups helped define the suitability of exoskeleton use; identified desirable patient characteristics; highlighted the importance of patient expectations and patient or caregiver training; described therapist benefits; and described device preferences, limitations, and recommendations. Results provide guidance to therapists in selection and application of robotic exoskeletons in practice.

Supplier

a. NVivo 12 Pro software; QSR International.

Keywords

Exoskeleton device; Focus group; Rehabilitation

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