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Background

Walking (gait) is a complex and unique motor activity that consists of three major components: movement, balance and the capacity to adapt to one's surroundings. Normal gait requires a delicate balance of multiple interacting systems, including three major afferent sensory systems, a locomotor efferent system and strict monitoring by several central nervous system structures. Gait irregularities in older people are a major source of functional impairment, lower quality of life, morbidity and even fatality due to their link to falls and resultant catastrophic fractures or head injuries. According to the clinical setting, 2.0% to 20.0% of patients were referred for mobility problems. Outpatient clinics have a functional movement issue, and 40.0% of these patients have gait abnormalities without a structural disability. Regrettably, neurological gait and balance impairments are notoriously difficult to cure. For patients with gait disorders, rehabilitation is one of the process of recovering or controlling damaged abilities. Rehabilitation aims to restore motor abilities through repeated, high-intensity and task-specific exercises. This process establishes new brain connections that enable the re-transmission of motor impulses. Over the years, numerous robotic systems have been used to rehabilitate patients by performing repeated task-specific tasks. Robotic assistive devices train patients' limbs to send and receive signals from the brain, resulting in enhanced motor function. These modern technologies, which feature interactive automation, sensors and dynamic control logic can operate with minimum involvement of physiotherapist participation. This strategy is claimed to maximise the expertise and time of physiotherapists, leading to more successful rehabilitation programs.

Objective

The objective of this technology review was to assess the effectiveness, safety, organisational issue and economic implication of lower limb exoskeleton as a therapy option for patients with gait abnormality.

Methods

A systematic review was conducted. Review protocol, search strategy and literature search was developed by the main author related to lower limb exoskeleton for gait therapy. The following electronic databases were searched through the Ovid interface: MEDLINE® All <1946 to 12th July 2024. Comparative searches were run in EMBASE, Cochrane Library, PubMed, USFDA and INAHTA database while further articles were retrieved from reviewing the bibliographies of retrieved articles. Only articles on humans were included in the review. There was no language restriction in the search. The most recent search was carried out on 12th July 2024.

Results and conclusion:

The initial searches yield a total of 9,085 citations. After assessing for eligibility criteria, 19 full text articles were subsequently retrieved and included in the review, which consists of one systematic review and meta-analysis, three systematic reviews alone, 12 randomised controlled trials, two cost-effectiveness analysis studies and one budget impact analysis study. The studies were conducted mainly in United States, followed by countries in Asia Continents (Malaysia and South Korea), Europe Continents (Austria, Switzerland, Italy and United Kingdom) and Australia.

Effectiveness:
There was large and high level of retrievable evidence to suggest lower limb exoskeleton improved gait impairment regarding patient-subjective outcomes relative to those who receive placebo or any conventional rehabilitation program. Findings in general indicated that:

a. Stroke (subacute, mild and chronic)
   i. Exoskeleton improved significantly in walking speed ($p<0.05$), 6-minute walking test (6MWT; $p=0.03$), gait distance ($p<0.0001$), muscle strength ($p<0.0001$) and balance ($p<0.0001$) as compared to baseline.
   ii. Exoskeleton improved significantly in lower limb joint angles and forces ($p<0.05$) as compared to baseline.
   iii. In severe impairment patients, the walking test favoured exoskeleton groups significantly ($p=0.0003$).
   iv. In haemorrhagic stroke patients, exoskeleton showed significantly higher on balance ($p=0.029$) and daily step count ($p=0.013$) as compared to control.
   v. Exoskeleton showed significant improvement in EuroQoL-5D (EQ-5D) score, Functional Ambulatory Category (FAC) score, Fugl-Meyer Assessment (FMA) scale iii -limb, Korean-modified Fall Efficacy Scale (K-F spatiotemporal measures and all gait symmetry as compared to the control group ($p<0.05$).
   vi. Exoskeleton showed significant impact on the electromyography amplitude of paretic muscles than in control group ($p=0.04$).

b. Spinal cord injury (SCI)
   i. Exoskeleton group showed the highest increase in self-selected gait speed and mean distance covered, as well as the shortest median time for timed-up-and-go, as compared to the control group.
   ii. Exoskeleton dominated control intervention significantly in the ambulatory assessment.

c. Multiple sclerosis
   i. Exoskeleton improved significantly in Symbol Digit Modalities Test (SDMT), thalamocortical resting-state functional connectivity, Functional Independence Measure (FIM) and Tinetti Balance Scale (TBS) ($p<0.001$) in 6 weeks.

Safety:
There was limited and high level of retrievable evidence suggesting that lower limb exoskeleton was generally safe with no device-related falls or serious adverse events, plus well-tolerated by patients during gait therapy. This device was not associated with death or hospitalisation, as well as has been approved by United States of Food and Drug Administration (US FDA) for medical purposes and registered in Medical Device Authority Malaysia.

Economic implication:
   i. In incomplete SCI, exoskeleton was not the most cost-effective alternative for an additional quality-adjusted life year (QALY) at any willingness-to-pay (WTP) level.
   ii. In complete SCI, when WTP exceeds $10,000 USD per QALY, exoskeleton showed the highest likelihood of being cost-effective. When comparing locomotor techniques in patients

with complete SCI, 75.0% of simulations showed that exoskeleton produced the greatest net gain.

iii. In patients with hip fracture, the exoskeleton was expected to be cost-effective in cardiovascular and dementia patients under the age of 75.

iv. In terms of leasing the device, the exoskeleton was not cost-effective until it increased patients' health-related quality of life (HRQoL) by 25.0% and had a risk ratio of falling of 0.625. Meanwhile, in terms of purchasing to be considered cost-effective, the device should increase patients' HRQoL by 48.0% and decrease secondary hip fracture by 50.0%.

v. Cost-savings would be achieved when the robotic exoskeleton life was prolonged to eight years.

Partial Economic Evaluation:

i. The total cost of a typical 27-session RAGT course is RM5,449.33. In contrast, the total cost for 27 sessions of traditional treatment is RM355.32. When compared to standard treatment, RAGT incurs an additional cost of RM5,094.01.

ii. The incremental cost-effectiveness ratio (ICER) was determined to be RM16,980.04 per efficacy unit, implying that for every one-unit increase in efficacy, RAGT costs an extra RM16,980.04 when compared to conventional treatment.

iii. The number of sessions per year and their efficacy (increasing the number of sessions improves cost-effectiveness), have the largest impact on the ICER, whereas human resource expenses have little influence (staffing modifications can result in considerable ICER improvements).

Organisational issues:

Prior to implementing exoskeletons, it should follow the principles and hierarchy of preventive measures, ensuring that their use first and foremost helps to eliminate or control the identified risk factor. Furthermore, their introduction in the workplace does not create new risks for users or third parties, or elicits a rejection response from those who must use them. Introducing new technology into the workplace needs a thorough evaluation of Occupational Safety and Health (OSH) by all parties concerned. The Framework Directive (89/391/EEC) specifies a design that prioritises human comfort and well-being. Depending on the technology, personnel must receive sufficient training to use exoskeletons successfully and safely. This training may need time and resources. Exoskeletons require continual maintenance to function properly. This scenario might result in increased expenditures and operational complexity.

Conclusion:

The comparison between lower limb exoskeletons and conventional rehabilitation highlights both the benefits and challenges associated with each approach. Lower limb exoskeletons can significantly enhance mobility and functional independence, allowing patients to engage in more active rehabilitation with no serious adverse events. They provide consistent support and can facilitate intensive training, which may accelerate recovery for some patients, especially in stroke, SCI and multiple sclerosis patients. However, these devices come with high upfront costs, maintenance expenses and the need for specialised training for both users and clinicians.