You have seen that exoskeletons have the potential to revolutionize rehabilitation programs following spinal cord injuries, such as paraplegia. They offer additional advantages, not seen in previously available solutions such as wheelchairs. Despite the fact that there are currently multiple exoskeletons commercially available from various brands, their accessibility in clinical settings remains limited. This can be accounted for by the high costs and a large amount of training that is needed to fully teach physiotherapists how to make use of the device for their patients. Clinical expertise is a prime requirement before the exoskeleton can be put to use in rehabilitation programs since there are many safety factors and risks associated with such a device. We will highlight two facets related to the use of exoskeletons for spinal cord injury rehabilitation: the basic design of exoskeletons and even more importantly proven health consequences.

The design perspective of exoskeletons

Exoskeleton Efficacy
In order to determine the usefulness of exoskeletons, it is needed to take a closer look at the efficacy of exoskeleton rehabilitation. Is it really worth all the extra time, effort, and money that are currently pumped into this technology? Most importantly, from a clinical health perspective, it is absolutely necessary that an exoskeleton is safe to use under all circumstances. Recently several reports have shown that exoskeleton training is indeed safe and can already be used in various settings to encourage overground ambulation in spinal cord injury patients. One of the studies that was conducted involved nine different European rehabilitation institutions and in all cases showed the safety, feasibility, and obtained training benefits of walking with an exoskeleton. The rehabilitation programs that were examined here, all involved 8-week training programs in which the patients were closely monitored. The results were promising, as only three dropped out due to ankle swellings caused by the device and another four showed some pressure injuries, but the latter group was still able to complete the studies. The study highlighted the potential health benefits not otherwise seen in current rehabilitation programs, thus underlining the potential efficacy of including exoskeleton in such programs. To just name a few: robotic exoskeletons reduce sitting time, increase walking and standing time, encourage social engagement with family, and show effects on cardiovascular health, body composition, level of physical activity, and last but not least quality of life.
Want to learn more about the details of this study regarding exoskeleton efficacy? You can find the scientific article here.

Fitting time of exoskeletons
You have seen that there are various brands of exoskeletons available. And that is just the tip of the iceberg, as many more are currently in development by either research groups or companies. All of these different exoskeletons contain similar basic components, but the exact measurements and working principle may vary. Often exoskeletons require specific measurements to custom fit the device to the operator before it can actually be produced. Aspects to consider are leg length discrepancy among people, variations in pelvic orientation, or variability in skin sensitivity to pressure ulcers. All of these facets should be considered before anyone wears any exoskeleton. In practice, this often means that about 10 to 30 minutes are required to safely fit subjects into an exoskeleton before walking can be initiated. On top of that, the device should be subject to regular safety checks.

Only once the fitting and safety checks have been completed, the device can actually be turned on. In addition to the device itself, subjects usually undergo an extensive physical examination that determines their eligibility to be included or excluded in a rehabilitation program that involves exoskeletons.
Each and every training session again, time is needed to adjust the exoskeleton to custom fit the particular participant. Thereby possibly limiting the actual training time during scheduled sessions. Another thing to realize is that the transfer into the exoskeleton also requires practice. Often this involves first practicing the transfer to a special mat or specifically designed type of chair, thereby increasing the likelihood of falling. To prevent the incidence of falls, training programs often require participants to retain good hand functions to facilitate a safe transfer. Future exoskeleton designs may be aimed at reducing both the fitting time and transfer complexity. Lastly, not every exoskeleton is as easy to use as the other. Some require a rather high level of intellectuality to control the input of the device, which further limits the eligibility of participants and reduces the accessibility of the technology. Some participants may just need a bit more training time to fully familiarise themselves with the device and get the same benefits out of it as their peers.

Exoskeleton speed
The final design issue we want to highlight to consider is the speed at which you want your exoskeleton to operate. Current exoskeletons offer a range of varying speeds but are often characterized by a very modest speed. Since walking with an exoskeleton is generally a lot slower than ordinary walking, speed may be a factor that impedes exoskeleton use in community environments. Nevertheless, the slow speed of gait execution does have advantages. It helps pilots to preserve their balance and prevents them from falling over every other step. Besides, the walking speed may also increase over time as operators gain more confidence and experience through continuous training. They use their motor learning strategies to, for instance, learn how to secure their balance. Yet, be cautious here, as most devices have mainly been tested indoors with flat surfaces only. If instead the exoskeleton were used outside or on uneven terrains, the speed will almost certainly be reduced. The exoskeleton brands that have currently been officially approved for use, were both designed for flat surfaces, and have shown to be inadequate in walking on muddy, pebbles or wet terrains. Obviously, this impedes the possible applications and limits use to prior known locations.
From a design perspective, the use of lighter materials in exoskeletons may pave the way towards increasing the ambulation speed. At the moment, available exoskeletons are heavy and therefore may also require a perfect physique of the operator. Lastly, if the aim is to use exoskeletons in a community setting, this means that also weather conditions should be considered such that the device can actually be used outside. To this end, waterproof designs are needed, and together with a focus on choosing lighter materials that will pave the way for broader use of exoskeletons.

Exoskeleton use from a health perspective

Level of spinal cord injury
You previously learned that the level of a spinal cord injury majorly influences the functionality someone retains after their injury. The higher the location of the injury, the more severe the effect and the bigger the implications for motor functions may be. As a result, exoskeletons often have certain guidelines regarding the maximum height of injury that a potential pilot may have. This particular level of injury cut-off is set, because exoskeletons require reasonable hand functions to hold and operate the device (for example when crutches are part of the design).

In addition, during exoskeleton walks, the pilot will have to initiate shifting of their body weight which again requires certain muscle activity. Unfortunately, a large number of paraplegics cannot benefit from exoskeleton technology because their level of injury currently falls beyond the approved range. This is for example the case in people with tetraplegia, a group representing about 55% (National Spinal Cord Injury Statistical Center) of the spinal cord injury population! Future developments in exoskeleton technology, will hopefully address this issue and provide increased accessibility to a larger part of the SCI population regardless of the height of injury. Examples include focusing on new input methods independent of hand functionality and platform walkers that would eliminate the need for crutches for stability.

Effect of body weight and body composition

Paraplegics often experience rapid weight gain right after their injury, due to limited physical activity and sticking to the same diet they were consuming prior to their incident. As a result, it has been reported that two-thirds of the SCI population are overweight, or even obese. Needless to say, a solution is needed. Exoskeletons may contribute to limit obesity among SCI patients, by reducing their time spent sedentary, increasing their overall level of physical activity, and improving parameters related to body composition, such as bone density and muscle mass. Unfortunately, the devices currently available do have limitations regarding body mass, and usually do not support pilots who weigh over 100 kg. However, this weight cut-off may encourage participants to make dietary changes and follow effective meal plans to maintain healthy body weight, thereby further benefiting their overall health. Research yet has to show whether exoskeleton training can independently result in weight loss or more importantly reduce body fat mass, without additional effects of changes in diet. Besides the weight itself, training in an exoskeleton may impact other parameters of body composition. For example, a reduction in fat mass has been demonstrated to improve cardio-metabolic health. More in-depth reports are needed that cover the effect of exoskeleton training on body weight and body composition, as currently, most results have only been preliminary.

Physical Activity

Paraplegics are often confined to their wheelchair, living a sedentary lifestyle with greatly increased sitting time. More and more research reports are pointing out the negative effects of prolonged sitting time, as this poses a risk factor for developing cardiovascular disease, cancer or just increases all-cause mortality. Overall health is often determined by means of analyzing someone's cardio-respiratory fitness. This term refers to the ability of the circulatory and respiratory systems to supply sufficient oxygen to skeletal muscles during physical activity. The primary measure is the VO2 max, which is the maximum rate of oxygen consumed and is inversely related to incidences of cardiovascular disease. People with spinal cord injuries are recommended to perform at least twenty minutes of moderate to high-intensity exercise three times per week in order to maintain cardio-respiratory health. Exoskeleton training may form an alternative method to achieve this amount of moderate-intensity training, though the exact level of intensity still has to be determined. Nevertheless, it is certain that exoskeleton training helps to decrease sitting time and increase the number of steps, duration, and distance of walking in SCI patients.

Walking facilitated by exoskeletons provides a means of passive movement of the lower extremities. No muscle contraction is needed, and therefore the movement is likely to be accompanied with very low oxygen uptake and energy expenditure during exoskeleton use. In order to benefit most of the exoskeleton ambulation, it would be interesting to combine this method with other methods that actually do stimulate muscle contraction and increase energy expenditure, as that might contribute more to increasing the overall level of fitness of participants. Needless to say, exoskeleton training is still rather exhaustive, especially in designs that require strong arm muscles to maintain balance with the crutches.

Range of motion

People with SCI often face incidences of contractures at the hips, knees, and ankle joints. A contraction is the condition of shortening and hardening of muscles or other tissues, regularly resulting in deformity and rigidity of joints. This condition may limit the possible range of motion of the joints, thereby disqualifying participants for walking in an exoskeleton, which again holds certain cut-off limitations. When the required range of motion is not met by potential participants, they are often encouraged to take part in stretching exercises to improve muscle flexibility around the joints. Such stretching programs may take up to six months before sufficient improvement in the range of motion has been achieved. Exoskeleton training may then further support the natural recovery of muscle flexibility and encourages compensatory muscle activity.

Bone health

People with spinal cord injuries often suffer from decreased bone health: osteopenia or osteoporosis. These diseases are progressive, which means that bone remodeling and demineralization of the bone tissue happens in a continuous process at rather high rates. It was reported that most of the bone loss occurs within the first twelve to twenty-four months after the spinal cord injury before it plateaus at a steady rate within three to eight years post-injury. Due to decreased bone density, paraplegics are prone to experience lower extremity fractures that take a long time to heal. In order to restore the weight-bearing ability of the broken bone, often standing frames or other assistive devices have to be exploited. Monitoring the bone health of people with SCI has become an essential element in rehabilitation programs. This monitoring is definitely needed before anyone can participate in exoskeleton ambulation, to ensure safe standing and weight-bearing properties prior to participating in training programs. Early research results show that it is likely that a considerable number of participants would be excluded from exoskeleton training programs based on their bone density scores. In addition, SCI participants still remain prone to fractures which is a considerable risk factor while walking in an exoskeleton. Guidelines on how to determine the risk for bone fractures need to be established, including what clinical biomarkers are the most suitable for determining this risk.

Pressure injuries

Pressure ulcers are one of the most common injuries seen in people with SCI. It is documented that 70% - 75% of patients will experience certain pressure injuries during their lifetime. The risk of those injuries is that they can develop into bad wounds and are very prone to additional infections, causing dramatic changes in skin structure that are tough to heal. This risk factor has implications for the possibility of exoskeleton use. Participants should be screened based on their medical history, such that prior to training it can be determined whether they are likely to benefit from exoskeleton training without exposure to too much skin pressure. Exoskeletons most commonly have straps to help pilots keep their posture while walking. These straps are often quite rigid and tight, to ensure that the participants' body (especially the points of rotation) remains aligned with the device at all times. However, the straps are also likely to cause additional shear stress to soft tissue, and with the diminished sensory function in people with SCI this may lead to pressure injuries. Therefore, close monitoring of the skin during and after training sessions is required. Moreover, some exoskeletons exhibit pressure sensors that constantly monitor the pressure exerted at the human-machine interfaces. Those sensors provide feedback about the level of pressure and thereby help to prevent pressure ulcers.

At the moment, the biggest challenge is for cutting edge exoskeleton technologies to reach the target population. Strict rules apply before exoskeletons are approved by the FDA and in addition, they are still very expensive. Therefore exoskeleton accessibility for people with SCI is still limited since only a few clinics currently offer rehabilitation programs including exoskeleton training. Clinicians should be well-trained in this technology and have a good understanding of the accompanying risks for participants. Future research should be focused on the mentioned limitations such that more individuals with SCI become eligible to benefit from this emerging technology.
Source: Robotic Exoskeletons