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Brief review

Robotic-Gait Training in Children and Adolescents with Cerebral Palsy: Choice of Settings and Improvement Opportunities

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Abstract: About 70% of children and adolescents with cerebral palsy experience gait impairments which affect their autonomy and well-being. Robotic-assisted gait training using the Lokomat is particularly promising for rehabilitation as it provides a standardized environment favoring the massive repetition of the movement, in which physical demands are low on the therapist and high training loads can be achieved. As no guidelines exist regarding training protocols and Lokomat settings, the goal of this study was to review the literature on Lokomat-assisted gait therapy and possibly make training recommendations. The twelve studies reviewed reported both positive and null effects of Lokomat training on gait. Half of the studies combined Lokomat with other types of training and only five used a control intervention to assess its benefit. Overall, training was administered 1-5 times per week for 20-60 minutes, over 1-12 weeks. Although Lokomat settings were not always described, progressively decreasing body-weight support and guidance, while increasing treadmill speed appear to be prioritized. The variety of training protocols and settings used did not allow pooling of the studies to assess effects of interventions on gait parameters in children and adolescents with cerebral palsy. This review highlights the need for homogenization of interventions so that clear guidelines can emerge and be applied in rehabilitation centers.

Keywords: cerebral palsy; locomotion; robotic rehabilitation; Lokomat; physiotherapy; pediatrics

1. Introduction

Walking plays a key role in functional autonomy and active involvement in social life. Impairments resulting from cerebral palsy (CP), such as muscle weakness, altered coordination, pain, spasticity, and poor balance lead to persistent gait disorders [1–3]. About 70% of children and adolescents with CP experience gait disorders which deteriorates over time [4]. Impairments include limited range of motion, reduced walking speed, increased double-support time, and poor endurance [1–3]. Due to the high impact these disorders have on the integration and quality of life of CP children and adolescents [5,6], gait rehabilitation is one of physiotherapists' top priorities.

Various training modalities exist for gait rehabilitation in individuals with neurological disorders. In the early nineties, body weight support treadmill training (BWSTT) was introduced for gait rehabilitation of this patient population. However, BWSTT is physically demanding and requires two physiotherapists to assist each leg's movements. As a result, training time is limited. Over the last decades, robotic-assisted gait training (RAGT) emerged as a promising modality for gait rehabilitation in individuals with neurologic disorders [7]. RAGT has been shown to be as effective as overground stepping with the support of physiotherapists [8]. Advantages, such as the possibility to achieve a high number of repetitions and reduced physical demands on the therapist, make RAGT a valuable training modality. Furthermore, this approach provides a standardized training environment and allows an objective assessment of gait improvements throughout rehabilitation [9]. A systematic review that investigated effects of RAGT in post-stroke participants showed that patients receiving such training were more likely to achieve independent walking than those who received gait training without robotic assistance [10]. To date, the most widely used robotic assistance for gait rehabilitation is the Lokomat (Hocoma AG, Volketswil, Switzerland) [11]. The Lokomat allows gait training on the treadmill using a partial body weight support (BWS) harness and robotic assistance (Guidance) for both legs. Treadmill speed, BWS and Guidance provided by the Lokomat are fully adjustable. In addition to providing multisensory and task-oriented rehabilitation, RAGT can be done in a safe and fun environment [12], thus maintaining a higher level of motivation and adherence to treatment, especially in the pediatric population.

Conversely to the adult population with neurologic disorders [13,14], the current evidence regarding the clinical effectiveness and applicability of Lokomat training in pediatrics is weak [15]. In fact, contradictory results have been reported on the effect of Lokomat training on gait parameters. Borggraefe et al. [16] observed a significant effect of Lokomat training on gross motor performance measured by the Gross Motor Function Measure (GMFM-66), walking speed, and walking endurance in children with CP. Consistent with their results, Schroeder et al. [17] reported significant improvements in the GMFM-66 scale and patients' self-perception of performance after training, which were maintained at an eight-week follow-up. However, the authors found no significant improvement in walking speed or endurance after Lokomat training. In a retrospective study, van Hedel et al. [18] reported significant improvements in comfortable walking speed and function, as measured by the WeeFIM test, but no increases in walking endurance or GMFM-66 were observed after Lokomat training. Later, Wallard et al., [19,20] highlighted significant improvements in knee and ankle sagittal kinematics, as well as in dynamic balance control following Lokomat training combined with virtual reality in children who walk in jump gait. Finally, recent studies [21,22] reported no change in gait patterns after training. The inconsistency of the results makes it unclear whether Lokomat training is truly beneficial to children with CP.

Several studies have highlighted the importance of the therapist in personalizing training [21,25–27]. Since there are currently no guidelines however, each clinic and even therapist may adjust training settings based on their own experience and training. Yet, there is some evidence from clinical trials that Lokomat settings might be important to achieve expected results [23,24]. As the patient groups trained are heterogeneous, and the optimal Lokomat settings are patient-dependent, evidence remain scarce in the current literature. To optimize the Lokomat therapeutic contribution, it is now appearing essential that guidelines for selecting appropriate Lokomat settings be generated. The purpose of this article was thus to summarize the current literature and generate clinical recommendations about training protocols and Lokomat settings, with the aim to improve gait in children and adolescent with CP.

2. Evidence of the Effectiveness of Robotic Gait Training in Children and adolescents with Cerebral Palsy

There is growing evidence that RAGT in CP children and adolescents improves areas of the International Classification of Functioning, Disability and Health (ICF), such as body structures and functions (e.g., muscle power, contractures, spasticity), activity (e.g., mobility), and participation [36]. Main effects of Lokomat training in children with CP are summarized in Table 1. Several studies [16,17,37–39] highlighted an improvement in gross motor function measured by the GMFM-66 or the WeeFIM. Regarding walking ability, some studies [16,21,39–41] reported an increase in walking speed while two studies did not observe a significant change in this outcome after Lokomat training [17,22,42]. In addition, two studies [21,43] did not highlight any effect on the locomotor pattern. However, one study reported a significant change in knee and ankle kinematics as well as better upper extremity control following Lokomat training combined with virtual reality [19]. Results from a second study by the same authors also showed improved dynamic balance during walking in children and adolescents with CP following Lokomat training [19]. Finally, only four of these studies [19,20,42,44,45] were completed in a randomized controlled process and only three of these studies [16,17,21] provided a short-term follow-up of the observed changes. Thus, despite the generally positive effects reported in some of the studies, no consensus has been reached regarding the effectiveness of Lokomat training.

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Table 1: Summary of the main clinical tirals on Lokomat training in children and adolescents with cerebral palsy.

Authors	Design	N of subjects	Intervention	ICF domains	Main results
Meyer-Heim et al., 2009	Pre/post	22 patients with CP; age = 5–12 yrs; GMFCS = II to IV	Lokomat training	Activity	Improvements in GMFM D and E scores; walking endurance (6-MWT) and walking speed.
Borggraefe et al., 2010	Pre/post with Follow-Up	20 patients with CP; age = 5–20 yrs; GMFCS = I to VI	Lokomat trianing	Activity	Improved GMFM-66 score; walking endurance (6-MWT), comfortable walking speed.
Druzbicki et al., 2013	RCT	35 patients with CP; age = 6–13 yrs; GMFCS = II - III	Lokomat training (n = 10) vs control group (n = 9)	Activity	Improvement in balance, step length and maximum hip flexion amplitude.
Klobucká et al., 2013	Pre/post	51 patients with CP; age = 4–27 yrs; GMFCS = I to IV	Lokomat training	Activity	Improvement in GMFM scores A, B, C, D and E scores; maximum walking speed and walking endurance (6-MWT).
Schroeder et al., 2014a, 2014b	Prospective controlled cohort	18 patients with CP; age = 5-21 yrs; GMFCS = I to VI	Lokomat training	Activity and participation	Significant improvement in GMFM-66 score and COPM (participation). Improvements were maintained after 8 weeks of follow-up.
Van Hedel et al., 2015	Retrospective	67 patients with CP; age = 4-20yrs; GMFCS II-IV	Lokomat training combined to conventional therapy	Activity	Improved function (as measured by the WeeFIM test) and walking speed.
Wallard et al. 2017, 2018	RCT	14 patients with CP (Jump gait) age = 8-10 yrs; GMFCS II - III	Lokomat training combined to virtual reality	Activity	Improvement of knee and ankle sagittal kinematics as well as dynamic balance control after Lokomat training combined with virtual reality.
Aras et al. (2019)	RCT	30 patients with CP; age = 6-4 yrs; GMFCS = II & III	Lokomat training (n = 10) vs antigravity training (n = 10), and BWSTT (n = 10)	Activity	Increased cadence, stride length, and stride time after anti-gravity training. Decreased double-support time was significant in the anti-gravity and Lokomat training. Increased GMFM-D, GMFM-E and walking endurance (6-MWT) in all the groups.
Ammann-Reiffer et al 2020	RCT	16 patients with CP; age = 6.0–15.3 years; GMFCS = II to IV	Lokomat training (n=8) vs control group (n=8)	Activity domain	Neither GMFM nor walking speed and endurance (6-MWT) changed significantly after Lokomat training.
Beretta et al., 2020	Retrospective	72 patients with CP; age = 4-18 yrs; GMFCS = I to IV	Lokomat training combined to conventional therapy	Activity	Improvement in walking endurance (6-MWT). No improvement in GMFM-88 scores.
Cherni et al., 2020	Pre/Post with Follow-Up	24 patients with CP; age = 7-20 yrs; GMFCS = II to IV	Lokomat training	Body function and activity	Increased hip and knee flexors and extensors' strength, comfortable walking speed (+20%), and step length (+14%). Increase in walking endurance (6-MWT) was maintained at follow-up. No change in gait pattern.
Petrarca et al., 2021	Pre/post	24 participants with CP; age = 4-13 yrs; GMFCS = I to IV	Lokomat training combined to conventional therapy	Activity	All improved GMFM D, while dimension E improved only for younger and more severely affected patients. No change in gait pattern.

NOTE: RCT: Randomized Controlled Trial; CP: cerebral palsy; GMFCS: Gross Motor Function Classification System; 6-MWT: six-minute walking test; GMFM: gross motor functional measurement; COPM: Canadian Occupational Performance Measure; BWS: body-weight support.

Table 2. Summary of training parameters and Lokomat settings.

Studies	Training parameters	Lokomat settings
Meyer-Heim et al., 2009	45–60 min per session, 3-5 sessions per week for 3-5 weeks	No information about Lokomat settings.
Borggraefe et al., 2010	50 min per session, 4 sessions per week for 3 weeks	Speed was set at 1.1 km/h and gradually increased to 1.8 km/h. BWS started at 100% and then decreased as much as possible. Guidance was adjusted according to clinical judgement. Progression of settings not described except for speed.
Druzbicki et al., 2013	45 min per session, 4 sessions per week for 5 weeks	No information about Lokomat settings.
Klobucká et al., 2013	20-25 min per session, 3-5 sessions per week for 5-6 weeks	Training speed ranged from 1.1 m/s for severely impaired patients to 1.8 m/s for the mildly impaired group.
Schroeder et al., 2014	30-39 min per session, 4 sessions per week for 3 weeks	No information about Lokomat settings.
Van Hedel et al., 2015	At least one session	No information about Lokomat settings.
Wallard et al. 2017, 2018	40 min per session, 5 sessions per week for 4 weeks	Speed was set at 0.7 km/h and gradually increased to 1.4 Km/h. BWS started at 70% and then decreased to 40%. No information about Guidance.
Aras et al. (2019)	45 min per session, 5 sessions per week for 4 weeks	Speed was set to the child's average walking speed. BWS started at 60% and gradually decreased to a level which prevented the collapse of the knee in flexion during the stance phase. No information about Guidance. Progression of settings not described.
Ammann-Reiffer et al., 2020	30-45 min per session, 3 sessions per week for 5 weeks	No information about Lokomat settings.
Beretta et al., 2020	45 min per session, 5 sessions per week for 4 weeks	For all patients, the same exercises were offered with set duration, speed, and difficulty. BWS started at 50% and gradually decreased according to the patient functional capacity. Guidance was initially set to 100% and gradually decreased. Progression of settings not described.
Cherni et al., 2020	30-45 min per session, 2 sessions per week for 12 weeks	Speed was set at 1.2 km/h and gradually increased to 1.8 Km/h. BWS started at 47% and then decreased to 22%. Guidance was initially set at 100% and gradually decreased to 65%.
Petrarca et al., 2021	30 min per session, 5 sessions per week for 4 weeks	No information about Lokomat settings.

3. Training Parameters & Settings

Training parameters (frequency, session duration and total duration of the intervention) are displayed in **Table 2**. In six study, the Lokomat training was combined to other therapy such as conventional therapy [22,41,43,44] or virtual reality [19,45]. In six studies [16,17,21,46–48], participants performed training with the Lokomat only. Five studies compared the effect of Lokomat training to a control intervention, such as conventional therapy [17,19,45,48,49] and anti-gravity or BWS treadmill training [42]. The training protocols presented across studies varied in intensity and duration (Table 2). Training was typically conducted with a frequency of 1 [41] to 5 sessions per week [19,22,39,45] with a duration of 20–60 min each each and spread across 1 [41] to 12 weeks [21], although most studies favored short interventions of 3-5 weeks of 3-5 weeks [16,17,19,22,39,43–45,48,50]. In conclusion, the proposed protocols are so far heterogeneous, and no clear recommendation can emerge from the current literature regarding optimal training parameters.

Description of Lokomat settings is presented in **Table 2**. Overall, these are only partially described in published clinical studies. Regarding the BWS, in four studies, support exceeded 50% of the body weight [19,20,50,51], other studies never decreased the support below 50% [21,52]. Current evidence suggests that reducing BWS leads to higher muscle activations [53,54]. Additionally, there is some evidence that BWS interacts with the effects of treadmill speed and Guidance [55]. Indeed, a high level of BWS attenuated the effects of treadmill speed and Guidance [55]. Concerning treadmill speed, general recommendation tends promote the increase of this setting as the patients improve [19,21,51,52]. Previous research suggests that an increase in treadmill speed increases the training intensity, one of the motor learning factors presented in figure 1, as showed by its effect on the heart rate [56]. In this same context, an increase in treadmill speed induced an increase in muscle activation in individuals with stroke and CP [55,57]. As for Guidance, current evidence suggests that walking ability improvement requires active physical participation of patients during intervention [58]. The current evidence comes mostly from cross-sectional studies and highlighted that a reduction of the Guidance can increase muscle activations [57,59–61]. Thus, therapists aim for a low Guidance, although this is not always possible. In children and adolescents with CP, the authors tended to start at high levels of Guidance and then decrease according to the patient's ability [21]. In general, studies point out that the effect of Guidance is less obvious than BWS or treadmill speed [54,61].

4. Discussion and Recommendations for Clinical Practice

This narrative review summarized the current literature on the use of RAGT on lower-limb function and/or gait parameters in children and adolescents with CP. Overall, Lokomat training showed some positive effects on lower-limb function, balance and spatiotemporal gait parameters in children and adolescents with CP. To date, despite the growing interest towards this technology, there are no guidelines to select the appropriate Lokomat settings. It is often difficult to replicate published intervention protocols in everyday clinical rehabilitation practice. This is mainly due to the complexity of interventions and the lack of information about protocols (e.g., training parameters, progression of settings) [62]. These aspects are often reported by rehabilitation professionals as a limiting factor to implement published interventions in their clinical practices. The present review is the first to summarize the settings used in previous studies with the aim to generate some clinical recommendations.

4.1. Training parameters

In motor rehabilitation, the concept of optimal dosing to lead to improvements in motor function in children and adolescents with CP is complex. The heterogeneity of samples and the variability of training frequencies, durations, and intensity complicates the development of guidelines for optimal training parameters [63]. In a general context, higher intensities and durations have a positive effect on gait rehabilitation [64] as they promote brain plasticity. Verschuren et al. [65] attempted to provide general recommendations for training dosage for children and adolescents with CP. The authors highlighted beneficial effects of longer-duration interventions (e.g., two or more sessions per week for 8-16 weeks) while progressively increasing training intensity [65]. Over time, most children and adolescents with CP present relatively severe locomotor disorders and are subject to early fatigue during prolonged exercise (e.g., continuous walking for 30-45 min). In this sense, Verschuren et al. [65] highlighted that longer-duration interventions allow these children to get used to activities perceived as difficult early on. In their systematic review, however, Cope & Mohn-Johnsen [66] pointed out that there was no evidence favoring high-frequency training over lower -frequency one in children and adolescents with CP [66]. Most Lokomat studies in children and adolescents with CP were based on short intervention duration (3-5 weeks) with high frequencies (4-5 sessions/week). Moreover, the two studies that reported a significant post-training change on gait pattern in children and adolescents with CP were those proposing short intervention (4 weeks) with high frequency training (5 times per week) [19,45]. It is however important to note that those studies present some limitations. First, they excluded children with severe impairments (GMFCS III and IV) who are the most at risk for losing their locomotor abilities. Second, the training frequency used would be difficult to control with children followed up on an outpatient basis. Finally, these studies did not report short-term follow-up after training. In conclusion, the lack of protocol reporting standardization makes the RAGT of patients with complex and varied neuromotor disorders such as CP challenging. In this context, we propose that feasibility studies should be conducted to assess the clinical relevance of existing protocol, and better understand the needs and barriers of their implementation.

4.2. Choice of settings

The variety of settings and the difficulty in defining those which are optimal for a specific patient group present an important barrier in achieving expected therapeutic goals following Lokomat training. Overall, initial BWS was variable in clinical trials with CP children and adolescents. Four studies [16,19,50] started with a BWS higher than 50%, whereas support in other studies never exceeded 50% of the body weight [21,52]. Indeed, previous cross-sectional studies reported that, high levels of BWS should be avoided, when possible, to achieve close-to-normative gait patterns [53,54,67]. Regarding treadmill speed, most of the included studies increased this setting as the patients improve. Previous studies suggest that an increase in gait speed should be promoted as it increases the heart rate and thus the intensity of therapy [68,69]. In addition, research on children and adolescents with CP suggests that an increase in walking speed increases the muscle activation [69]. Regarding the robotic assistance, current evidence suggests that recovery/learning requires active physical participation of patients during therapy [40], thus a low level of Guidance should be favored. More specifically at Lokomat, a reduction of Guidance can increase the muscle activation [53]. However, other studies have concluded a less obvious effect of Guidance on muscle activity and coordination [54,60]. As an approach to optimize the settings, Cherni et al. [26] developed a method that uses electromyography to detect Lokomat settings that induce higher muscle activations in hip extensors in post-stroke individuals. This study was however a proof-of-concept with only two participants. Though promising, the method thus still needs to be validated in a larger sample and with other patient groups. As of today, there is a noteworthy lack of reported information on Lokomat settings, limiting the understanding of the impact of RAGT in children and adolescents with CP and the replication of proposed protocols in clinical practice. Thus, the therapist’s experience and judgment remain essential to personalize and better adjust the Lokomat settings [70].

4.3. Effectiveness of Lokomat training

Based on the ICF model, RAGT studies focused on the effect of training on locomotor activity and very little on body function/structure and participation. However, body functions and structures are major determinants of walking ability of children and adolescents with CP [71]. Regarding participation domain, although it is rarely directly measured, dependent variables, such as comfortable walking speed and walking endurance, are highly associated with participation [5,71,72]. After Lokomat training, significant improvements in lower limb strength [21], walking speed [18,21,46,47,51], step length [21,49], walking endurance [21,46,47,50–52] and GMFM [17,46,47,50–52,73] were observed in children and adolescents with CP. The improvements in GMFM score [17], endurance [21] and COPM [17] were maintained over time. Despite the promising effect of RAGT on walking ability, the majority of studies did not show any significant changes in gait pattern in children and adolescents with CP. Cherni et al [21] reported a trend of changes in hip extension ($p = 0.08$) and knee flexion ($p = 0.09$) peaks during the stance phase and concluded that potentially two training sessions per week were not enough to significantly change the gait of CP children. In addition, the heterogeneity of the participants' gait patterns included in their study could also explain for the absence of significant effects on gait patterns. In fact, Wallard et al. [19] reported significant improvements in gait patterns of a homogenous patient group (i.e., CP children who walk in jump gait only) after Lokomat training using a higher training frequency protocol (e.g.,5 sessions per week). Using the same training frequency, Beretta et al [52] observed no effect on gait patterns of children and adolescents with CP following Lokomat training combined with conventional therapy. In any case, such high training frequency is often difficult to apply in clinics since it requires a considerable investment in time and effort for the children and adolescents who go to school and their parents.

4.4. Patient-specific determinants of responsiveness

Given the important heterogeneity that could characterize the CP population, some studies evaluated effects of Lokomat training as a function of the participants' ages [43] and baseline gross motor functions as measured by the GMFCS or GMFM [21,41,43,74]. Schroeder et al. [74] highlighted that GMFM levels at baseline and age were identified as relevant determinants of responsiveness to RAGT. Indeed, the results showed that patients with higher motor abilities at baseline improved more following Lokomat training than those with lower gross motor abilities. The authors also reported that the effect on GMFM-D improvement was inversely associated with age [74]. A recent study by Petrarca et al. [73] showed a mild improvement of GMFM-D in all subjects, while dimension E changed only in the younger and more severely affected patients. In a clinical context, therapist rarely have GMFM baseline values to guide their decision making. Rather, it is common for them to rely clinical decision making on GMFCS levels. In addition, it has been shown that children and adolescents with levels I and II of GMFCS show similar developmental curves which differ from those with levels III and IV [4]. While investigating the benefit of RAGT as a function of GMFCS levels, Hedel et al. [18] reported that children with severe impairments (GMFCS III—IV) may benefit more from Lokomat training than children with moderate impairments (GMFCS II). In their study, children with GMFCS II level showed no significant improvement in mobility as measured by the WeeFIM, walking speed, or endurance. However, as in their study participants received Lokomat training in complement to conventional therapy, it would have been difficult to isolate Lokomat-induced improvements from those caused by other therapies. These results contradict those of Cherni et al. [21] who highlighted a significant improvement in muscle strength, walking speed, step length, and endurance in children with GMFCS level II, as well as those with severe impairments (GMFCS levels III—IV). The disparity of observations in relation to determinants of responsiveness to RAGT does not allow to determine a patient profile that is more likely to improve after training. The current evidence thus highlighted that Lokomat training has a positive effect on walking ability regardless of the patient's baseline level in gross motor function.

4.5. Perspectives

In terms of future research, further clinical trials should aim for higher quality designs that are reproducible. Moreover, multi-site collaborations would facilitate the recruitment of large sample sizes, which would enable generalization of the results and making inferences based on severity of the impairments. Assessing effects of Lokomat training in the medium and long terms by conducting post-training follow ups would also contribute to evaluating the effectiveness of this robotic technology. Future studies should integrate models such as the ICF to help guide and standardize the assessment of RAGT (e.g., body function and structure, activities and participation) in children and adolescents with CP. In addition, there is a need to develop methods that will help better select RAGT settings according to a therapeutic objective. For example, by using electromyography to select the settings that will involve most a deficient muscle group. Additionally, methods must be developed to determine the optimal dose and intensity of the training. For example, intensity during training can be monitored and quantified by using accelerometers or heart rate monitors. These tools could also provide information about the patient's daily life-based gait performance, as a complement to laboratory-based assessments, improving the understanding of the patient's overall gait challenges and shaping the goals developed with the families and children.

5. Conclusions

This article summarized intervention protocols, Lokomat settings, and main effects of Lokomat training on children and adolescents with CP. Heterogeneity of the studies did not allow the generation of guidelines and highlighted the need for protocol standardization in reporting intervention protocols Indeed, standardization will be essential to ensure that the Lokomat is used to its full potential to provide greatest possible gait benefits to this population.

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