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CYCLING EXERCISE DURING HEMODIALYSIS USING A SERIOUS GAME: A FEASIBILITY STUDY

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ABSTRACT

Chronic kidney disease (CKD) has a worthwhile impact on public health, with an estimated global prevalence of 11 to 13%. Uremic sarcopenia is a typical consequence in these patients. It can cause physical disability and reduce autonomy and quality of life. Game therapy has emerged as a promising therapeutic tool in rehabilitation, effectively addressing essential elements such as attention, motivation, and repetitiveness. This study aimed to design and evaluate the feasibility of a biomedical system created to encourage cycling exercise during hemodialysis, incorporating a serious game as a key component. Thirteen patients were involved in the study: 8 women and 5 men. The average age was 47.2 (±12.3) years. Time on hemodialysis was 52.6 (±31.1) months. The assessment protocol includes handgrip strength (HGS) by dynamometry, the 5 times sit-to-stand test (5x SST), and the gait speed test (GST). An average of 20 sessions were carried out twice a week, each taking 20 to 25 minutes. Patients showed significant improvements at the end of treatment, especially in HGS ($p=0.05$) and 5x SST ($p=0.03$). Preliminary results on the feasibility of the resource through the Likert scale satisfaction index were: 77% very satisfied, 23% satisfied, and no patient indicated dissatisfaction with participation in the sessions during the study. Good results in the measurements of controlled variables and strong patient acceptance show great promise for the rehabilitation of individuals with kidney disease.

Keywords: Chronic Kidney Failure; Hemodialysis; Serious Games; Technological Rehabilitation.

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INTRODUCTION

Approximately 850 million people worldwide are estimated to have kidney disease, most of whom live in low-income and lower-middle-income countries (FRANCIS *et al*., 2024). Chronic kidney disease (CKD) has an important impact on public health with an estimated global prevalence of 11–13% (NICOLL *et al*., 2018). As many as 9 out of 10 individuals in resource-poor settings with weak primary care infrastructure are unaware that they have this condition and therefore do not seek treatment. In contrast to cardiovascular disease, stroke, and respiratory disease, CKD mortality has been rising (FRANCIS *et al*., 2024).

Sarcopenia is a risk factor for adverse clinical outcomes in CKD patients, including mortality. Diagnosis depends on the adopted consensus definition and cutoff values, and the prevalence rates are generally heterogeneous (DUARTE *et al*., 2024). According to the Revised European Consensus, sarcopenia is currently considered a muscle disease. Diagnostic criteria are based on the assessment of strength, muscle mass, and functional performance. Currently, muscle strength is the central and most important criterion (CRUZ-JENTOFT *et al*., 2019).

While sarcopenia is widely acknowledged as a common condition among older people, CKD has emerged as a significant contributor to musculoskeletal impairments. This link is primarily attributed to CKD-related metabolic abnormalities and chronic systemic inflammation. Increasing research supports a direct correlation between advancing CKD stages and higher rates of sarcopenia (DUARTE *et al*., 2024).

CKD patients are at increased risk for falls and fractures, as well as decreased quality of life and mobility due to musculoskeletal system impairments. Multiple CKD-related changes negatively impact muscle size and function (TROUTMAN *et al*., 2022). As CKD progresses, it contributes to the accumulation of uremic toxins, the release of pro-inflammatory cytokines, and the onset of systemic inflammation. This progression is also marked by heightened oxidative stress, the emergence of insulin resistance, and various post-translational modifications of proteins. Bone-related changes are, in part, mediated through communication between myokines and osteokines, which contribute to muscle metabolism changes that can impair skeletal muscle in CKD, and thus develop the so-called uremic sarcopenia (TROUTMAN *et al*., 2022). This severe muscle impairment is a frequent finding in CKD, especially in patients with more advanced stages undergoing hemodialysis, as these patients have chronic kidney failure (CKF) (SABATINO *et al*., 2021).

Exercise therapy plays a crucial role in managing CKD and CKF, offering numerous benefits that can mitigate the progression of these conditions and enhance patients' quality of life. A large multicenter study, cluster randomized controlled trial evaluated combined endurance and resistance exercise training during hemodialysis *versus* usual care in CKF. It assessed physical functioning, quality of life, hospitalizations, and overall survival. Twelve months of intradialytic exercise in patients with CKF significantly improved their physical performance compared with usual care (ANDING-ROST *et al*., 2023). However, exercise interventions to improve muscle size and function demonstrate inconsistent responses that warrant further investigation to optimize exercise prescription (TROUTMAN et *al*., 2022).

Game therapy has emerged as a promising therapeutic tool, effectively addressing essential elements of rehabilitation such as attention, motivation, and repetitiveness (BENTO *et al*., 2018; MAYNARD *et al*., 2019). In particular, so-called Serious Games (SG) can represent a worthwhile resource in the rehabilitation of these patients, since these games are designed for a specific purpose, and are therefore easier to customize the therapy implemented (SOARES *et al*., 2016).

Recognizing the harmful impact of uremic sarcopenia on CKF patients, this study sought to design and evaluate the feasibility of a biomedical system aimed at encouraging cycling exercise during hemodialysis through the use of a serious game.

METHODS

The study was approved by the Ethics Committee for Research with Humans (number 5,590,358), and the procedures followed the Helsinki Declaration. All participants signed an Informed Consent Form. This study was carried out at the Pró-Rim Foundation in Joinville, Santa Catarina, Brazil. In this first phase, the aim was to test the feasibility of using a biomedical system designed for intradialytic rehabilitation of CKF patients.

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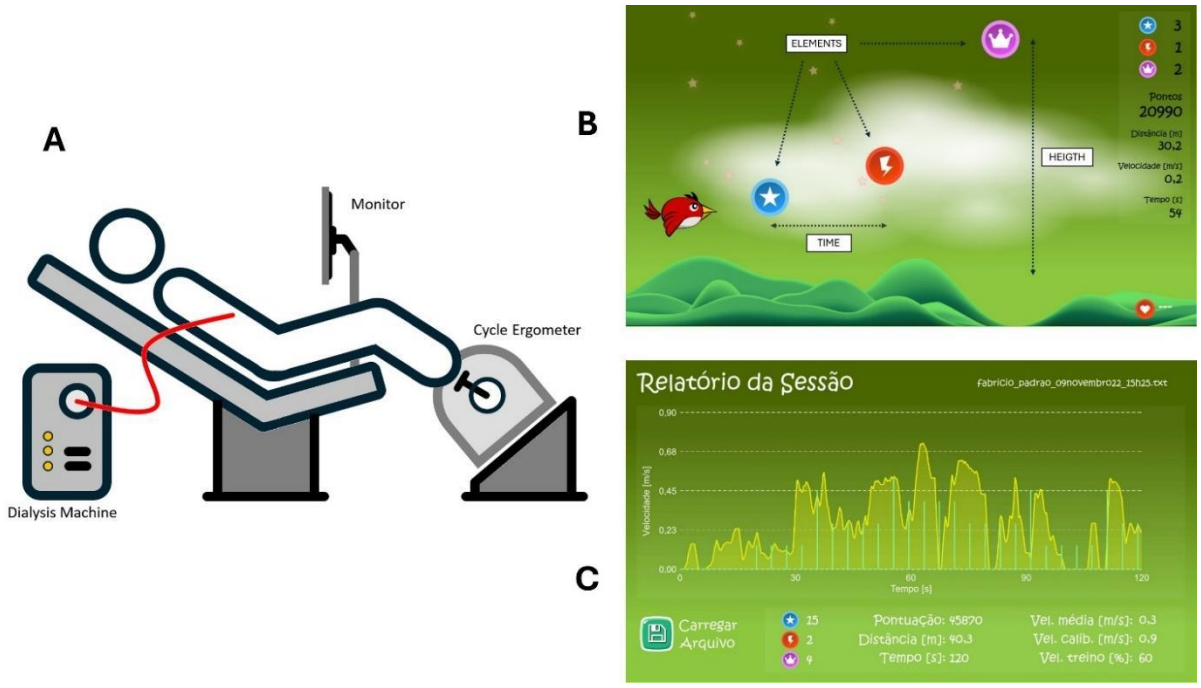
The assessment protocol includes handgrip strength by dynamometry, the 5 times sit-to-stand test, and the gait speed test.

The biomedical system designed for the study comprises a cycle ergometer adapted with specific hardware and a serious game. The serious game (SG), called *goBit-bike*, aims to control a character to collect objects that appear in the game environment. The physiotherapist defines the locations where the objects appear on the screen according to the therapeutic goals of the session. The character, a bird named Bit, moves vertically based on the pedaling speed of the cycle ergometer: the faster the pedaling speed, the higher the bird flies. The speed is measured using data obtained from a magnetic sensor (Hall effect sensor) and a set of four neodymium magnets appropriately attached to the pedal axis. The data generated are processed by a microcontroller system based on Arduino and sent to the computer to control the game. The *goBit-bike* SG is a 2D game developed using Unity, a cross-platform game engine widely used for creating games. The visual elements of the game are simple and designed to keep the patient focused on the task of collecting objects that move toward the bird and are aligned with the therapeutic goals. The SG was developed by a specialized team consisting of an engineer and a physiotherapist. Figure 1 shows the main components of the system (A), the graphic elements of the serious game (B), and the session report (C).

Figure 1. Biomedical system developed.



The sessions were controlled using the standard Borg rating of perceived exertion scale, in addition to hemodynamic variables, such as blood pressure (every 5 minutes), oxygen saturation, and heart rate (LAMBERT *et al*., 2022).

Data were analyzed using the GraphPad Prism 8® software. The Shapiro-Wilk test was used to verify the normality of the data. To evaluate differences between pre- and post-test, the student's t-test was applied for parametric data, and Wilcoxon's test for non-parametric data. A significance level of 5% ($p<0.05$) was adopted for all tests. In addition, the effect size (*d*) was calculated for each variable controlled in the study.

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RESULTS

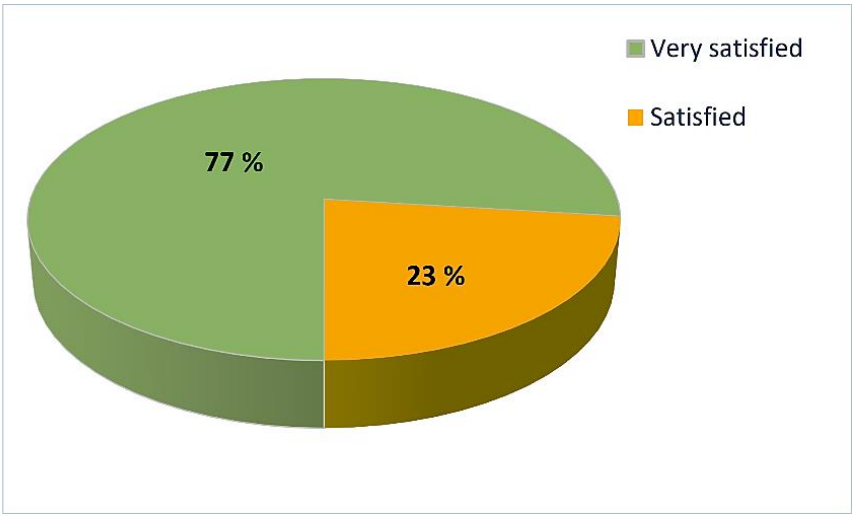
Thirteen patients were involved in the study: 8 women and 5 men. The average age was 47.2 (±12.3) years. Time on hemodialysis was 52.6 (±31.1) months. An average of 20 sessions were carried out twice a week, each taking 20 to 25 minutes. The summary of the results is presented in Table 1.

Table 1. Summary of results.

	Pre $\bar{x}$ (±)	Post $\bar{x}$ (±)	*p*-value	*d*
Handgrip strength (kgf)	26.9 (11.2)	29.5 (11.5)	0.05	0.23
5x sit-and-stand test (s)	12.1 (4.5)	10.6 (3.6)	0.03	0.37
Gait speed test (m/s)	1.42 (0.38)	1.53 (0.36)	0.08	0.30

To find out about patients' acceptance of and interest in exercise sessions during hemodialysis using the biomedical system designed for the study, the researchers used a Likert scale to assess the level of satisfaction (Figure 2).

Figure 2. Level of satisfaction by Likert scale.



Regarding the level of satisfaction in participating in the study, the results were encouraging, as the vast majority felt very satisfied with the therapy. The patients reported different positive perceptions, such as motivation, pleasure in exercising with the game, and the association of therapy with improved physical and mental health. These aspects should be better explored as the study continues. No patient indicated dissatisfaction with taking part in the sessions during the study.

No complications were observed in terms of hemodynamic variables during the sessions.

DISCUSSION AND CONCLUSIONS

This study aimed to assess the feasibility of the therapeutic use of a biomedical system consisting of an adapted cycle ergometer associated with a serious game on CKF patients undergoing hemodialysis.

There seems to be strong evidence of the risk of developing uremic sarcopenia (AVESANI *et al*., 2023; DUARTE *et al*., 2024; SABATINO *et al*., 2021; TROUTMAN *et al*., 2022). And that physical exercise has several benefits (ANDING-ROST *et al*., 2023; HALLE *et*

al., 2024; LAMBERT *et al*., 2022; SONG *et al*., 2022; WILUND; VIANA; PEREZ, 2020).

Preliminary results showed that patients improved functional performance with the implemented training. These results are in line with previous studies (ANDING-ROST *et al*., 2023; HALLE *et al*., 2024; MAYNARD *et al*., 2019; SONG *et al*., 2022; YOUNG *et al*., 2018). Regarding the gait speed test, which presented a p-value of 0.08 (not significant), the difference between the pre- and post-test measurements was 0.11 m/s. This difference is considered clinically significant (between 0.10 and 0.20) (BOHANNON; GLENNEY, 2014). Probably a transfer of function, since there was no gait training during the experiment.

Incorporating new technological resources into the clinical practice of physiotherapy is becoming increasingly worthwhile and necessary (E SIQUEIRA; PARRAÇA; SOUSA, 2024). This is especially true since the routine related to hemodialysis sessions is very difficult and painful. Therefore, finding a more pleasurable way to encourage patients to exercise during this procedure seems an excellent strategy (SOARES *et al*., 2016).

Our preliminary findings in this feasibility study have shown how these patients can accept the most enjoyable approach. Meeting key requirements such as increased attentional demand, motivation, and repetitiveness are implicit in sessions with serious games (SOARES *et al*., 2016).

Although it is a feasibility study, and the preliminary results are interesting, it is important to indicate the limitations of the study, such as the small number of patients involved in the study, the absence of a control group, and blinding in the evaluation process. These problems will be remedied with the new study design planned for the continuation of the research project. We are very encouraged by the patients' great acceptance and believe that this resource is indeed promising in the rehabilitation of patients with kidney disease.

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