




# Telemedicine-Supported Exercise Interventions in Hematopoietic Stem Cell Transplantation: A Scoping Review

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**Background:** Hematopoietic stem cell transplantation is a potentially curative therapy for various hematologic conditions. Though physical exercise has been shown to positively affect physical and psychosocial function in patients undergoing hematopoietic stem cell transplantation, they often face multiple barriers to accessing comprehensive exercise-based rehabilitation programs. Telemedicine has emerged as a promising strategy to overcome these challenges by facilitating remote exercise interventions and potentially improving patient outcomes.

**Objective:** This scoping review aimed to map the current landscape of telemedicine-supported exercise interventions in hematopoietic stem cell transplantation, assessing their clinical and technical characteristics, feasibility, effectiveness, and gaps in the literature.

**Methods:** Following the Arksey and O'Malley framework and subsequent enhancements, we systematically searched MEDLINE, SCOPUS, Web of Science, and Embase from inception to July 31, 2024. We included experimental studies examining telemedicine-supported exercise interventions for hematopoietic stem cell transplantation recipients and extracted data on study design, participant characteristics, technology used, exercise modalities, and outcomes measured. Findings were synthesized narratively.

**Results:** Our search resulted in 1116 papers, with 10 included in the final review. Most studies (90%) focused on feasibility and employed prospective designs, including quasi-experimental (60%) and randomized controlled trials (40%). Sample sizes were generally small, with 80% of studies enrolling fewer than 50 participants. Aerobic exercise was the most frequently implemented modality (80%), with reported improvements in VO<sub>2</sub>peak, 6-minute walk test performance, and quality of life. Functional outcomes were assessed in 90% of studies, while 50% evaluated quality-of-life metrics. Interventions were largely feasible, safe, and acceptable, overcoming barriers to care for hematopoietic stem cell transplantation patients.

**Conclusion:** Telemedicine-supported exercise interventions are feasible and show promise in improving physical function and quality of life for hematopoietic stem cell transplantation patients.

**Keywords:** telemedicine, hematopoietic stem cell transplantation, telerehabilitation, exercise, scoping review

## Introduction

Hematopoietic Stem Cell Transplantation (HSCT) is a well-established curative therapy for a broad spectrum of conditions, particularly malignant hematologic diseases, as well as select nonmalignant congenital and acquired diseases of the hematopoietic system.<sup>1</sup> Since the first transplantation performed more than 6 decades ago,<sup>2</sup> the use of HSCT has steadily increased. This growth can be attributed to expanding indications, improved patient selection, less toxic conditioning regimens, and enhanced supportive care measures.<sup>2,3</sup> While HSCT has significantly improved survival rates, patients who undergo this procedure remain at heightened risk for a range of late complications, including graft-versus-host disease (GVHD) and disease relapse, as well as unique long-term sequelae related to the transplant itself.<sup>4</sup>

Over the past two decades, accumulating evidence has underscored the critical role of exercise in both the prevention and management of cancer.<sup>5</sup> Targeted physical activity interventions have demonstrated substantial benefits in improving physical function, quality of life (QoL), and reducing cancer-related fatigue in various patient populations, including

those who have undergone HSCT. In fact, the American College of Sports Medicine assigns a high level of evidence to the safety and efficacy of aerobic and strength training for adults during or after HSCT.<sup>6</sup>

Despite these established benefits, numerous barriers often limit patient access to comprehensive cancer rehabilitation services. Socioeconomic factors, transportation challenges, employment obligations, financial costs, and time constraints can all impede patients from receiving consistent in-person exercise-based interventions.<sup>7,8</sup> In this scenario, telemedicine has emerged as a promising strategy to deliver specialized care remotely. By leveraging digital communication tools, telemedicine can enhance access to post-HSCT services, reduce the logistical and financial burdens associated with frequent in-person visits, and maintain close patient monitoring even when individuals are deemed clinically unstable.<sup>9</sup>

Although telemedicine holds considerable promise for optimizing care delivery and long-term management in HSCT populations, its implementation, effectiveness, and overall impact have not been comprehensively explored. This gap in the literature warrants a systematic examination to identify current telemedicine applications, evaluate their feasibility and effectiveness, and highlight areas requiring further investigation. Accordingly, this scoping review aims to map the current landscape of telemedicine-supported exercise interventions in HSCT, assessing their clinical and technical characteristics, feasibility, effectiveness, and gaps in the literature.

## Methods

### Study Design

This scoping review was conducted following the framework proposed by Arksey and O'Malley,<sup>10</sup> with enhancements suggested by Levac et al<sup>11</sup> and the Joanna Briggs Institute (JBI) Manual for Evidence Synthesis.<sup>12</sup> Our methods adhered to the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews<sup>13</sup> (See [Table S1](#)).

### Information Sources and Search Strategy

A comprehensive search was conducted in the following databases: MEDLINE (via PubMed), SCOPUS, Web of Science, and Embase. We used controlled vocabulary (eg, MeSH terms) and keywords related to telemedicine and hematopoietic stem cell transplantation (eg, “telemedicine”, “telehealth”, “HSCT”). The search included studies published from database inception to July 31, 2024, without language restrictions. Search strategies for each database are detailed in [Tables S2–S5](#).

### Study Selection

We included experimental studies, such as randomized and non-randomized clinical trials, as well as quasi-experimental designs (eg, pre-post studies) that were published as peer-reviewed articles, letters, or short communications. The eligible studies reported results on telemedicine-supported exercise interventions pre-, during, and post-HSCT. Additionally, documents reporting any type of healthcare services related to HSCT delivered via telehealth were also included. Conversely, we excluded secondary research studies, including systematic reviews, umbrella reviews, and scoping reviews; however, references within these studies were consulted to identify relevant primary research. Other exclusions included protocols, opinions, case reports, case series, and non-peer-reviewed documents.

The study selection process involved two stages and was conducted using the Rayyan.ai platform. In the first stage, two independent reviewers screened the titles and abstracts of all identified studies. Any disagreements between the reviewers were resolved by a third reviewer. In the second stage, the full texts of selected articles were retrieved and assessed against the predefined eligibility criteria. To ensure consistency in the application of inclusion and exclusion criteria, a pilot screening of 11 documents was conducted prior to the formal selection process. This pilot exercise allowed for standardization of the reviewers' approach and refinement of the criteria.

### Data Charting Process

We developed a standardized data charting form, capturing key information on study design, participant demographics, telemedicine technical features, therapeutic approaches, and outcomes evaluated. This form was piloted on two studies to

ensure its clarity and comprehensiveness. Data extraction was conducted independently by two pairs of reviewers. Any discrepancies in data extraction were resolved through discussion or consultation with a third reviewer.

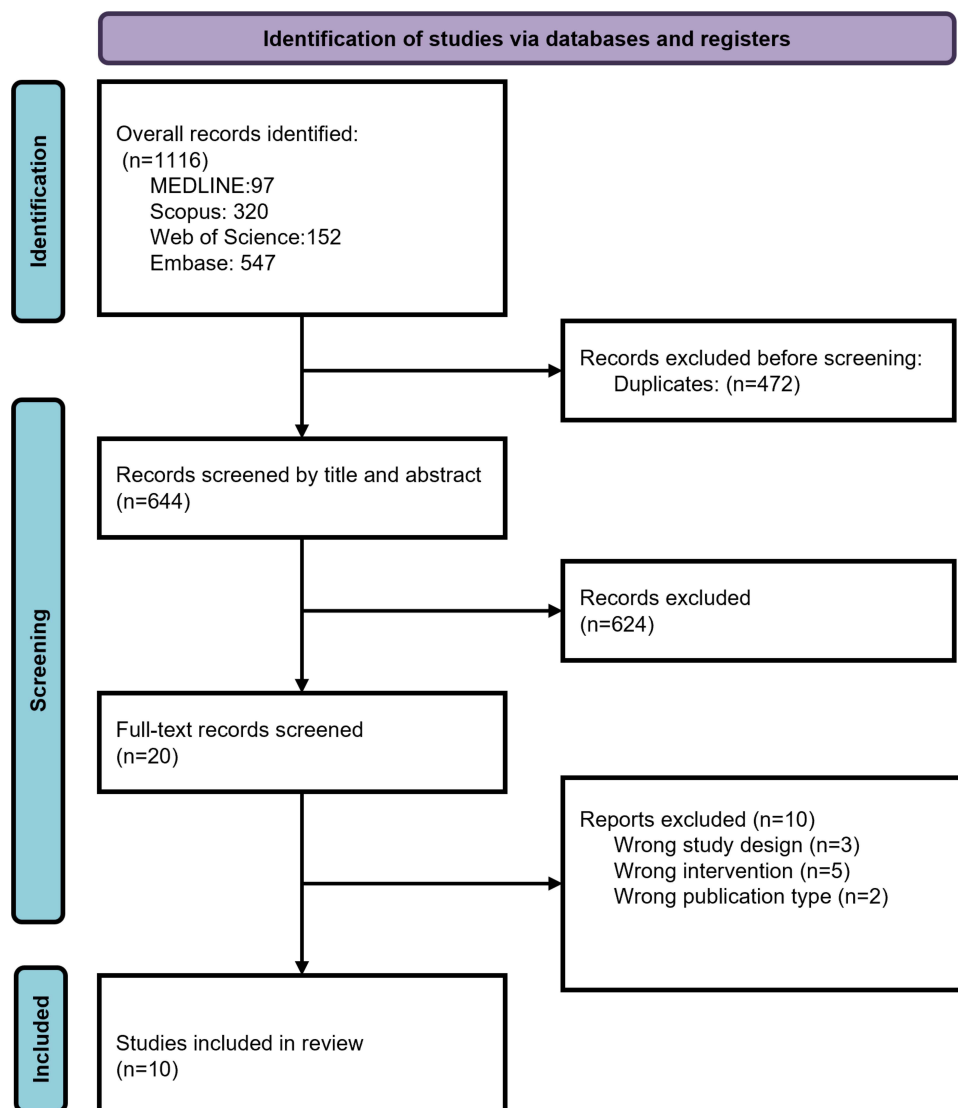
## Data Synthesis

Data were synthesized narratively and presented using descriptive statistics and cross-tabulation to illustrate the main findings. We synthesized information on the study designs, technical characteristics of telemedicine interventions, therapeutic approaches used, and outcomes assessed. The results were categorized based on themes identified during the data extraction phase, and tables were generated to provide a detailed summary of the studies included.

## Results

### Selection Process

We found in our query research 1116 potential papers to be included in the study. After duplicates were removed, 644 reports were screened by title and abstract, 624 of them were excluded and we found 20 relevant documents to the research question. All these studies were then read in detail, resulting in 10 articles to be included in the final study.<sup>14–23</sup> Specific reasons for excluding the remaining full-text articles are provided in [Table S6](#). This process is detailed in [Figure 1](#).



**Figure 1** PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart of the study search and exclusion process.

## General Characteristics

**Table 1** describes the findings regarding the main characteristics of the studies and participants. The included studies were published between 2005 and 2024, with the highest concentration in 2023 (30%, n=3).<sup>20–22</sup> Most studies were conducted in the United States (70%, n=7),<sup>14,16–18,20,21,23</sup> with the remaining studies carried out in Germany,<sup>15</sup> Australia,<sup>19</sup> and the United Kingdom (10% each).<sup>22</sup>

The majority of studies (90%, n=9) focused on feasibility,<sup>14,16–23</sup> with quasi-experimental designs predominating (60%, n=6).<sup>14,16,18–20,23</sup> Half of the studies (n=5) included one arm,<sup>14,18–20,23</sup> while the other half included two arms.<sup>15–17,21,22</sup> All studies followed prospective designs. Half of the studies (n=5) were single-arm pre-post studies,<sup>14,18–20,23</sup> one of them being a study that includes dyads of patient-caregiver.<sup>23</sup> Randomized controlled trials (RCTs) were present in 40% of studies.<sup>15,17,21,22</sup> Among these, two RCTs evaluated outcomes across two time points (pre- and post-intervention),<sup>17,21</sup> another across four time points (2 pre-HSCT and 2 post-HSCT),<sup>15</sup> and one across three time points (1 pre-HSCT and 2 post-HSCT).<sup>22</sup> The sample sizes were limited, with 8 out of 10 studies (80%) enrolling fewer than 50 participants.<sup>14,16–21,23</sup> The details on inclusion of patients with autologous (auto) and allogeneic (allo) HSCT as well as patients with GVHD are delineated in **Table 1**.

## Participants Characteristics

Regarding gender distribution, 8 studies (80%) reported a higher proportion of men,<sup>15–20,22,23</sup> whereas only one study (10%) included more women,<sup>14</sup> and another (10%) had equal representation of men and women.<sup>21</sup> Age characteristics were reported in various formats. Mean ages were provided 60% of the studies and ranged from 48.8 to 64.7 years.<sup>14,15,20–23</sup> Median ages were reported in 3 studies (30%) and ranged from 52 to 60.5 years.<sup>16,17,19</sup> Age ranges were described in 5 studies (50%), spanning from as young as 18 to as old as 76.4 years.<sup>15,17–20</sup>

Regarding diagnoses, leukemia<sup>15–21,23</sup> and lymphoma<sup>14,16–21,23</sup> were the most frequently studied conditions, with both being addressed in 8 out of 10 studies (80%). Multiple myeloma followed, appearing in 70% (n=7) of studies.<sup>14–17,21–23</sup> Most interventions were conducted after HSCT (50%, n=5),<sup>14,18,19,21,23</sup> while 30% (n=3) were conducted before transplantation<sup>16,17,20</sup> and 20% (n=2) spanned from before to after HSCT.<sup>15,22</sup>

## Technology Used

As show in **Table 2**, phone calls and medical devices were the predominant technologies, used in 80% (n=8)<sup>14–18,20,22,23</sup> and 70% (n=7)<sup>14,16,17,20–23</sup> of studies, respectively. Videoconferencing was reported in 4 out of 10 studies (40%).<sup>19,20,22,23</sup> Fewer studies incorporated web systems (20%, n=2),<sup>21,23</sup> mobile apps (10%, n=1),<sup>20</sup> or SMS (10%, n=1).<sup>20</sup> Various medical devices were used, including smart-watches (n=4, 40%),<sup>16,17,20,23</sup> heart-rate monitors (n=2, 20%),<sup>14,22</sup> and gait sensors (n=1, 10%).<sup>21</sup> Most studies relied on one (30%, n=3)<sup>15,18,19</sup> or two (40%, n=4)<sup>14,16,17,21</sup> technologies, while fewer incorporated three or more (n=3, 30%).<sup>20,22,23</sup>

## Exercise Program Details

**Table 3** summarizes exercises modalities and exercise prescription approaches reported in the reviewed articles. Seven out of 10 studies (70%) reported self-directed exercise programs,<sup>14–18,20,23</sup> while 30% (n=3) were guided by healthcare providers.<sup>19,21,22</sup> Half of the studies present hybrid exercise delivery (home and clinic) (n=5),<sup>14,16,17,21,23</sup> with 2 studies (20%) with this delivery of exercise among the whole period of the intervention<sup>15,22</sup> and 3 studies (30%) presenting this modality for the initial sessions.<sup>18–20</sup> Aerobic exercise was the most common modality, included in 80% (n=8) of studies.<sup>14–17,19,20,22,23</sup> Resistance exercises were implemented in 5 out of 10 studies (50%),<sup>15,18,19,21,22</sup> whereas flexibility and other exercises, such as mindfulness-based stress management and balance training, appeared in fewer studies.

Exercise program durations ranged from 6 to 15.3 weeks, with some studies reporting unclear durations (n=1, 10%).<sup>15</sup> The most frequently reported session length was 30 minutes, described in 40% (n=4) of studies.<sup>16,17,20,21</sup> Most of the studies reported some way of intensity goals for the exercise programs (n=7, 70%),<sup>14–17,19,20,22</sup> being HRR the most frequent intensity indicator (n=3, 30%),<sup>14,20,22</sup> followed by MHR (n=2, 20%),<sup>16,17</sup> and the Borg Perceived Exertion Scale

**Table 1** Study Design and Participants Characteristics

Article	Country	Aim of the Study and Type of Study	Specific Design	Sample Size	Participants Characteristics (Allo – Allogeneic, Auto – Autologous Transplantation; GVHD – Graft-versus Host-Disease)	Type of Cancer	Intervention and Stage of SC Transplantation
Wilson et al, 2005 <sup>14</sup>	USA	Feasibility Quasi-experimental Study	Prospective, single-arm, pre-post study	Total=17	Sex: 68.8% female (11/17). Age: mean=48.9 ± 10.4. Race: Caucasian=12, Hispanic=3, African American=1; Middle eastern=1. N(allo)=4; N(auto)=13; N(GVHD)=1.	Multiple Myeloma Other cancers Lymphoma	After HSCT
Wiskemann et al, 2010 <sup>15</sup>	Germany	Effectiveness RCT	Prospective, 2-arms, randomized controlled trial, 4-time points evaluation (2 pre HSCT, 2 after HSCT)	Total=105, T=52 and C=53	Sex: 32.4% female (34/71). Age: mean= 48.8, range=18-71. N(allo)=105; N(auto)=0; N(GVHD)=39.	Leukemia Myelodysplastic Syndrome/ Myeloproliferative Neoplasm Multiple Myeloma Lymphoma Aplastic Anemia	Before, during and after HSCT
Wood et al, 2016 <sup>16</sup>	USA	Feasibility Quasi-experimental Study	Prospective, 2-arms, without control group, pre-post study	Total=40, Autologous (T1)=20 and Allogenic (T2)=20	Sex: 35% female (14/40). Age: T1 median=60.5 and T2 median=52.5. N(allo)=20; N(auto)=20; N(GVHD)= not mentioned.	Leukemia Multiple Myeloma Myelodysplastic Syndrome/ Myeloproliferative Neoplasm Lymphoma Aplastic Anemia Other	Before HSCT
Wood et al, 2020 <sup>17</sup>	USA	Feasibility RCT	Prospective, 2-arms, randomized controlled trial, 2-time points evaluation (pre-post)	Total=28. T=13 and C=15	Sex: 43% female (12/28). Age: median=52, range=28-73. Race: White=19, Black=6, Other=3. N(allo)=16; N(auto)=0; N(GVHD)= not mentioned.	Leukemia Myelodysplastic Syndrome/ Myeloproliferative Neoplasm Lymphoma Multiple Myeloma Aplastic Anemia Other	Before HSCT

(Continued)

Table 1 (Continued).

Article	Country	Aim of the Study and Type of Study	Specific Design	Sample Size	Participants Characteristics (Allo – Allogeneic, Auto – Autologous Transplantation; GVHD – Graft-versus Host-Disease)	Type of Cancer	Intervention and Stage of SC Transplantation
Ketterl et al, 2021 <sup>18</sup>	USA	Feasibility Quasi-experimental Study	Prospective, single-arm, pre-post study	Total=20	Sex: 30% female (6/20). Age: range=16-39. Race: White=17, Black or African American=1, Asian=2. N(allo)=16; N(auto)=4; N(GVHD)= 11.	Leukemia Lymphoma Other Cancer	After HSCT
Ma et al, 2022 <sup>19</sup>	Australia	Feasibility Quasi-experimental Study	Prospective, single-arm, pre-post study	Total=21	Sex: 43% female (9/21). Age: median=56. Race: not mentioned. N(allo)=21; N(auto)=0; N(GVHD)= 1.	Leukemia Lymphoma Other	After HSCT
Artese et al, 2023 <sup>20</sup>	USA	Feasibility Quasi-experimental Study	Prospective, single-arm, pre-post study	Total=13	Sex: 23.1% female (3/13). Age: mean=58.8, range=34.2–76.4. Race: White=10, Black or African American=3. N(allo)=13; N(auto)=0; N(GVHD)=0.	Myelodysplastic Syndrome/ Myeloproliferative Neoplasm Leukemia Lymphoma	Before HSCT
Lee et al, 2023 <sup>21</sup>	USA	Feasibility RCT	Prospective, 2-arms, randomized controlled trial, 2 points of evaluation (pre and post)	Total=20, T1=10 and C=10	Sex: 50% female (10/20). Age: mean=64.7 ± 9.1. Race: Non-Hispanic White=4, Hispanic White= 4, African American=2. N(allo)=12; N(auto)=8; N(GVHD)= 11.	Lymphoma Leukemia Myelodysplastic Syndrome/ Myeloproliferative Neoplasm Multiple Myeloma	After HSCT
McCourt et al, 2023 <sup>22</sup>	United Kingdom	Feasibility RCT	Prospective, 2-arms, randomized controlled trial, 3 time points evaluation (1 pre HSCT, 2 after HSCT)	Total=50, T=23 and C=27	Sex: 38% female (19/50). Age: Tmean= 59.3 ± 9.4 and Cmean=61.3 ± 8.7. Race: White=37, Black=10, Asian=1, Other=2. N(allo)=0; N(auto)=35; N(GVHD)=0.	Multiple Myeloma	Before, during and after HSCT
Langer et al, 2024 <sup>23</sup>	USA	Feasibility Quasi-experimental Study	Prospective, single-arm (dyads), pre-post study	T=34. Patient=17 and Caregiver=17	Sex: 47.1% female (16/34). Age: mean= 55.6. Race: White=32, Other=2. N(allo)=9; N(auto)=8; N(GVHD)=1 (mentioned).	Leukemia Lymphoma Multiple Myeloma Myelodysplastic Syndrome/ Myeloproliferative Neoplasm	After HSCT

**Abbreviations:** RCT, randomized controlled trial; T, treatment group; C, control group; HSCT, Hematopoietic stem cell transplantation; Allo, allogenic; Auto, autologous; GVHD, graft-versus-host disease.

**Table 2** Intervention Characteristics

Article	Technology Used to Deliver Exercise Program	Exercise Location and Guidance	Exercise Program Description	Duration, Frequency, Time per Session, and Intensity of the Program	Monitoring of Performance	Outcomes Measured
Wilson et al, 2005 <sup>14</sup>	Medical device (heart rate monitor), and phone calls.	Home-based and clinic, health provider guided	Aerobic: Patients were allowed to select a preferred mode of exercise (ie walking, cycling, swimming, exercise tapes).	Period: 12 weeks Frequency: 3–5 days per week Time per session: 20–40 minutes Intensity: 40–60% HRR	Self-directed using paper-log and HR monitor measurements. Asynchronous via weekly telephone call by research personnel (unclear specialty).	Participants demonstrated significant improvements in aerobic fitness, fatigue severity, and physical well-being during program participation ( $P < 0.05$ ). The findings suggest that individually prescribed, home-based aerobic exercise is an acceptable, safe, and effective intervention to enhance physical functioning and reduce fatigue in sedentary HSCT recipients.
Wiskemann et al, 2010 <sup>15</sup>	Phone calls.	Home-based, health provider and ICT guided	Aerobic and Resistance: Walking, bicycling, treadmill, Nordic walking or jogging. Strength training included exercises for the upper and lower extremities.	Period: Unclear Frequency: 2–5 days per week Time per session: 20–40 minutes Intensity: Borg scale (12–14 for endurance and 14–16 for resistance exercises)	Real-time differed monitoring weekly via phone calls by research staff.	The exercise group experienced up to 15% improvement in fatigue scores, compared to a deterioration of up to 28% in the control group ( $P = 0.01–0.03$ ). Additional benefits included significant improvements in physical fitness/functioning ( $P = 0.02–0.03$ ) and reductions in global distress ( $P = 0.03$ ).
Wood et al, 2016 <sup>16</sup>	Medical device (Polar FTI heart rate monitor, and Fitbit Flex accelerometer), and phone calls	Home-based, health provider and ICT guided	Aerobic (HIIT): Each session consisted of five, 3 min intervals of walking, jogging or cycling at 65–95% maximal heart rate (MHR) with 3 min of low-intensity exercise (65% MHR) between intervals.	Period: 6 weeks Frequency: 3 days per week Time per session: 30 minutes Intensity: Week 1 to 2= 60–70% MHR. Week 3 to 6= 65–95% MHR	Weekly real-time differed monitoring by research personnel via phone call	Cardiorespiratory fitness was enhanced between pre and post intervention with significant $VO_{2peak}$ (median increase 1.1 mL/kg*min, $P=0.12$ ) and 6MWD (median increase 30.1 m, $P=0.19$ ) variations.

(Continued)

Table 2 (Continued).

Article	Technology Used to Deliver Exercise Program	Exercise Location and Guidance	Exercise Program Description	Duration, Frequency, Time per Session, and Intensity of the Program	Monitoring of Performance	Outcomes Measured
Wood et al, 2020 <sup>17</sup>	Medical device (Fitbit heart-rate monitor and accelerometer), and phone calls.	Home-based with weekly call by the provider	Aerobic (HIIT): Available local training resources and choose one or more modes of exercise (from a list that included walking, jogging, running, cycling, elliptical, or stair climbing)	Period: 8.5 weeks (range 3–20 weeks) Frequency: 3–4 days per week Time per session: 30 minutes Intensity: 80% MHR or beyond	None	The design of the prehabilitative intervention was deemed infeasible in this pilot study, limiting the ability to draw definitive conclusions regarding its impact on VO <sub>2</sub> peak and 6MWD changes. Recommendations were made for future research to refine the intervention design.
Ketterl et al, 2021 <sup>18</sup>	Phone calls.	Home-based and clinic, health provider guided	Resistance: Each participant was prescribed a progressive resistance program, with participants completing one to two sets of eight to 10 exercises, eight to 12 repetitions	Period: 12-weeks Frequency: 2–3 days per week Time per session: Unclear Intensity: Unclear	Weekly phone calls done by exercise physiologist	Post-intervention strength assessments revealed significant improvements across all measured domains, including gait speed, handgrip strength, and other physical performance metrics.
Ma et al, 2022 <sup>19</sup>	Videoconference (Skype).	Home-based and clinic, health provider guided	Aerobic and resistance: Training was comprised of moderate intensity exercises with stretching adapted according to patient needs and ability	Period: 6 weeks Frequency: 3–5 days per week Time per session: 60 minutes Intensity: Borg Scale (11 and 14)	The initial in-person training session was followed by five one-on-one personalized training sessions for each of the PE and MBSM components of the program. These sessions were conducted via videoconference using Skype at pre-scheduled times on a weekly basis and, each was approximately 60 min in duration.	Six-minute walk test performance improved significantly at 3 months (mean difference: 79.6 m; 95% CI: 28–131, ES: 0.55) and 12 months (mean difference: 48.4 m; 95% CI: 13–84, ES: 0.33). Sit-to-stand test performance improved by 4.4 repetitions at 3 months (95% CI: 1.4–7.4, ES: 0.68) and 3.9 repetitions at 12 months (95% CI: 0.24–7.6, ES: 0.61). Handgrip strength also increased significantly at both time points. Participants reported high satisfaction with the 6-week virtual program, which resulted in sustained improvements in physical capacity and quality of life.

Artese et al, 2023 <sup>20</sup>	Mobile app, medical device (Apple Watch smartwatch, an iPhone), SMS, videoconference, and phone calls.	Home-based, health provider guided	Aerobic (HIIT): Training at home or a location of their choice (ie outdoors trails, medical fitness center, etc).	Period: 15.3 ± 8.9 weeks Frequency: 3 days per week Time per session: 30 minutes Intensity: High-intensity= 80–90% HRR. Low-intensity= 50–60% HRR	The first home-based session was supervised via video conferencing. After the first session, participants completed the rest of the training sessions unsupervised. They were given a paper log to track exercise session dates and times.	Participants prescribed high-intensity HR training (68.8 ± 34.8% of intervals) achieved significant increases in VO <sub>2</sub> peak from 14.6 ± 3.1 to 17.9 ± 3.3 mL/kg/min (P < 0.001). Functional outcomes also improved, with notable gains in 30-second sit-to-stand repetitions (from 13.8 ± 1.5 to 18.3 ± 3.3 seconds) and 6MWT distance (from 514.4 ± 43.2 to 564.6 ± 19.3 m). These changes exceeded the minimal clinically important differences recognized in chronic disease populations.
Lee et al, 2023 <sup>21</sup>	Web-based telehealth platform, and medical device (gait sensors for hips, right foot, and left foot).	Home-based, health provider guided	Resistance and Balance: Each exercise session consisted of exercises targeting four essential components (dynamic balance, strength, core stability and postural control)	Period: 8 weeks Frequency: 3 days per week Time per session: 30 minutes Intensity: Unclear	None	Improvements in gait speed and handgrip strength were clinically meaningful, given their established associations with reduced mortality risk (27% increased mortality per 0.1 m/s decrease in gait speed; 4% reduced mortality per 1 kg increase in handgrip strength). There was no significant change in fatigue levels in none of the groups.

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Table 2 (Continued).

Article	Technology Used to Deliver Exercise Program	Exercise Location and Guidance	Exercise Program Description	Duration, Frequency, Time per Session, and Intensity of the Program	Monitoring of Performance	Outcomes Measured
McCourt et al, 2023 <sup>22</sup>	Medical device (heart-rate monitor), videoconference platform (Zoom), and phone calls.	Home-based and clinic, health provider guided	Aerobic and Resistance: All exercise was individually tailored according to ability	Period: Prehabilitation Phase: about 4 weeks During Transplant Admission: between hospital admission and discharge Rehabilitation Phase: 8 weeks Frequency: 3 days per week Time per session: 15–40 minutes Intensity: 60–80% of HRR	Phase 1 and 3: Supervised sessions in hospital-based gym by physiotherapist or real-time monitoring using videoconference by physiotherapist Phase 2: Self-directed at home	Within-group improvements beyond the minimal important difference (MID) were observed in the prehabilitation phase (T0–T1) for fatigue (FACIT-F) and quality of life (FACT-G and FACT-BMT) in the exercise group, but not in the control group. While quality of life deteriorated during admission for ASCT, it improved during the rehabilitation phase (T2–T3), highlighting the potential for exercise to support recovery.
Langer et al, 2024 <sup>23</sup>	Medical device (Fitbit Inspire 2 heart-rate monitor and accelerometer), videoconference platform, web-based platform, and phone calls.	Home-based, health provider guided	Aerobic: Weekly individualized step prescription based on the 75th percentile ranked value of their last 7 recorded daily step counts	Period: 8 weeks Frequency: Unclear Time per session: Unclear Intensity: Unclear	Asynchronous monitoring via web-based interface link to smart watch by research staff	Step counts among participants increased significantly over the intervention period, rising from 2249 ± 302 steps/day in week 1 to 4975 ± 1377 steps/day in week 8. Caregivers also saw increases from 8676 ± 3760 steps/day in week 1 to 9838 ± 3723 steps/day in week 8. Participants provided qualitative feedback citing perceived mental and physical health benefits, along with suggestions for adaptations to address medical constraints.

**Abbreviations:** HR, heart rate; HIIT, high intensity training; HRR, heart rate reserve; MID, minimal important difference; FACIT-F, Functional Assessment of Chronic Illness Therapy–Fatigue questionnaire; FACT-G, Functional Assessment of Cancer Therapy – General; FACT-BMT, Functional Assessment of Cancer Therapy - Bone Marrow Transplant; ICT, Information and Communication Technology; MHR, Maximum heart rate; VO<sub>2</sub>peak, peak oxygen uptake; 6MWT, 6-minute walking test; CI, confidence interval.

**Table 3** Exercise Description

Exercise Type	Exercise Description	Exercise Prescription
Aerobic Exercises	Walking <sup>14,16,17,19,20,22,23</sup> Brisk walking <sup>15</sup> Cycling <sup>14-17,19,20,22</sup> Treadmill <sup>15,22</sup> Nordic walking <sup>15</sup> Jogging <sup>15-17,20</sup> Swimming <sup>14,19</sup> Exercise tapes <sup>14</sup> Running <sup>17,19</sup> Elliptical <sup>17</sup> Stair climbing <sup>17,20</sup>	40 and 60% (moderate intensity) of age-predicted heart rate reserve <sup>14</sup> Borg scale (target scores 12–14 for endurance) <sup>15</sup> 65–95% maximal heart rate (MHR) <sup>16</sup> 80% MHR or beyond <sup>17</sup> Borg Scale (11 and 14) <sup>19</sup> High-intensity= 80–90% HRR. Low-intensity= 50–60% HRR <sup>20</sup> 60–80% of HRR <sup>22</sup> Weakly step goals <sup>23</sup>
Strengthening exercises	Upper and lower extremities with and without a set of color-coded stretch bands with different levels of resistance <sup>15,18,19,21,22</sup>	Increase band resistance (8–20 repetitions, 2 or 3 sets) <sup>15,18,21,22</sup> Borg scale (target scores 14–16 for resistance exercises) <sup>15</sup> Borg Scale (11 and 14) <sup>19</sup>
Flexibility	Stretching <sup>15,18,19</sup>	Cool-down stretching <sup>15</sup>
Balance	Dynamic balance <sup>21</sup>	Exercise programs were individualized and prescribed based on participants baseline assessment, physical limitations, and exercise preferences <sup>21</sup>
Relaxation	Mindfulness <sup>19</sup>	Guided mindfulness tracks <sup>19</sup>

**Abbreviations:** MHR, maximum heart rate; HRR, heart rate reserve.

(n=2, 20%).<sup>15,19</sup> Only 2 studies (20%) explicitly mentioned the use of any behavioral change theory or technique to guide the exercise intervention.<sup>22,23</sup>

Regarding monitoring performance, most studies (n=5, 50%) delivered in a differed way (after the exercise session) by phone-calls (n=4, 30%)<sup>14-16,18</sup> or web-interface connected to medical devices (n=1, 10%).<sup>23</sup> Three studies conducted monitoring during the exercise session using videoconference services (30%).<sup>19,20,22</sup>

## Outcomes Measured

Functional outcomes were reported in the majority of studies (90%, n=9)<sup>14-22</sup> likely feasibility outcomes which appeared in 90% (n=9).<sup>14,16-23</sup> Quality of life was evaluated in 5 out of 10 studies (50%).<sup>14,15,17,19,22</sup> Usability outcomes were less common, included in only 20% (n=2) of studies.<sup>19,20</sup> Adverse events were monitored in 60% (n=6) of studies,<sup>14-16,19,20,22</sup> though no reactions attributable to exercise were reported.

Across the included studies, exercise-based interventions delivered via telemedicine demonstrated varied and meaningful outcomes for patients undergoing hematopoietic stem cell transplantation (HSCT). Significant improvements in physical fitness and functioning were observed, including increases in VO<sub>2</sub>peak from 14.6 ± 3.1 to 17.9 ± 3.3 mL/kg/min (P < 0.001).<sup>20</sup> Sustained improvements in the 6-minute walk test (6MWT) were reported, with mean differences of 79.6 m (95% CI: 28–131) at 3 months and 48.4 m (95% CI: 13–84) at 12 months, along with improvements in sit-to-stand repetitions and handgrip strength.<sup>19</sup> Gait speed and handgrip strength improvements were described as clinically meaningful due to their associations with reduced mortality risk.<sup>18,21</sup> Functional outcomes, such as step counts, also increased significantly during interventions, with one study reporting an increase from 2249 ± 302 steps/day in week 1 to 4975 ± 1377 steps/day in week 8 for participants, while caregivers saw an increase from 8676 ± 3760 to 9838 ± 3723 steps/day during the same period.<sup>23</sup>

Interventions positively influenced quality of life and fatigue outcomes. Improvements in quality of life, measured by FACT-G and FACT-BMT, and fatigue, measured by FACIT-F, exceeded minimal important differences during the intervention

periods.<sup>22</sup> However, declines in quality of life were noted during hospitalization phases, such as autologous stem cell transplantation (ASCT), followed by recovery improvements during rehabilitation phases.<sup>22</sup> The exercise group in one study experienced a 15% improvement in fatigue scores compared to a 28% deterioration in the control group ( $P=0.01-0.03$ ).<sup>15</sup>

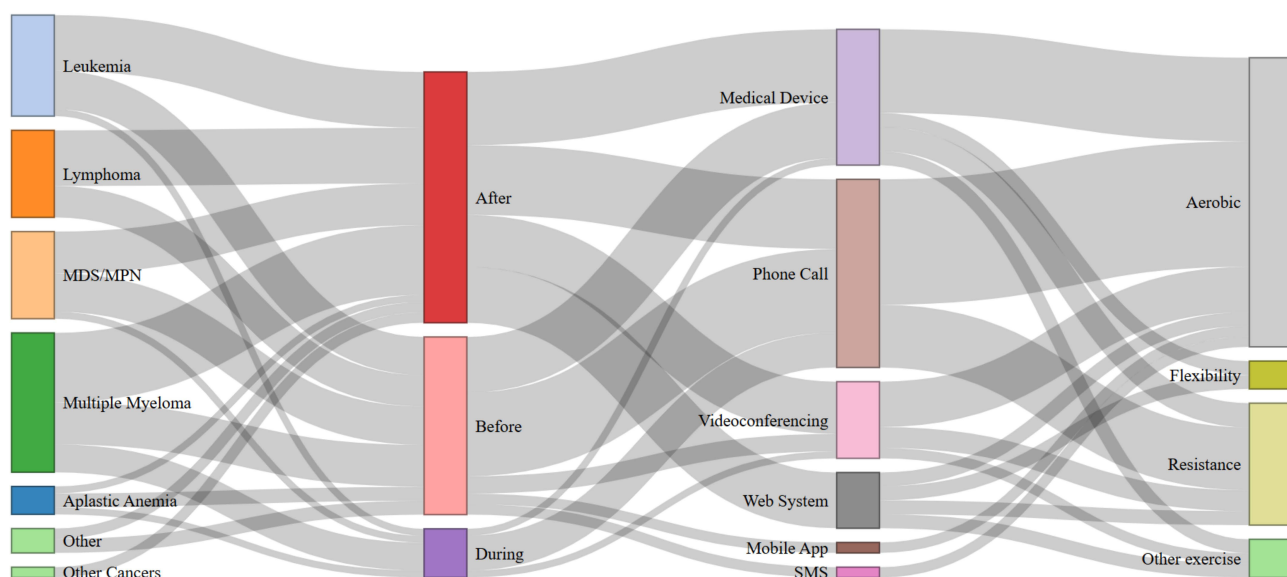
Home-based aerobic and resistance exercises were frequently implemented and well-accepted, with studies reporting their safety and effectiveness.<sup>15,19</sup> High-intensity interval training programs also yielded significant functional and physiological gains, with observed changes surpassing clinically important thresholds.<sup>20</sup> However, one pilot study reported feasibility challenges with its prehabilitation design, limiting its ability to draw definitive conclusions and underscoring the need for refined future interventions.<sup>17</sup>

## Discussion

### Principal Results and Comparison with Prior Work

This review aimed at mapping the current state of research regarding the clinical and technical applications of telemedicine in the context of HSCT. Ten eligible articles reporting experimental results were used for a critical overview of the current landscape and informing future research directions of the telemedicine-supported exercise interventions in patients undergoing HSCT. Although the number of eligible studies was limited, collectively they suggest that telemedicine modalities, ranging from telephone-based consultations to videoconferencing and wearable devices, can effectively support exercise programs for HSCT recipients before, during, and after transplantation (Figure 2). Across these studies, telemedicine-facilitated exercise regimens were generally found to be feasible, acceptable, and safe. Importantly, patients who engaged in these interventions often experienced improvements in functional capacity, including enhanced VO<sub>2</sub>peak, 6-minute walk test performance, handgrip strength, and 30-second sit-to-stand test scores, as well as better quality of life outcomes.<sup>14-23</sup>

The outcome improvements resulting from telemedicine-supported exercise programs in HSCT patients are analogous to the outcome improvements reported in the comprehensive reviews of in-person exercise interventions conducted in both allo- and auto-HSCT patients.<sup>24-26</sup> A systematic review and meta-analyses of randomized controlled trials assessing impact of physical exercise for patients undergoing hematopoietic stem cell transplantation demonstrated sufficient evidence that recipients of HSCT benefit from physical exercise.<sup>27</sup> DeFor et al found that physical exercise provided numerous benefits for HSCT patients, including enhancing both physical and emotional recovery after transplant therapy and potentially speeding up their return to health and functionality following the procedure.<sup>28</sup> The review by Morishita et al concluded that physical exercise is beneficial for the physiological, psychological, and psychosocial health of allo-HSCT patients.<sup>24</sup> This review recommended encouraging patients to perform physical exercise before, during, and after transplantation, and stated



**Figure 2** Relations between key characteristics of the included studies.

that physical exercise should be integrated into the conditioning and recovery plans for all allo-HSCT patients.<sup>24</sup> Those results are very well aligned with the findings from the studies included in this review.

The results of this review are in concordance with the recent report by Gandhi et al<sup>9</sup> concluding that telemedicine-supported physical activity yields positive results in patients undergoing HSCT. Gandhi et al underscored the potential of telemedicine-supported exercise in frail patients whose functional reserve can be significantly enhanced while following home-based exercise program.<sup>9</sup> These recommendations are especially relevant in the light of the fact that not only the overall numbers of HSCT are increasing, but HSCTs in adults over 70 years old are increasing at an even greater rate.<sup>24,25</sup> Incorporating telemedicine into exercise interventions will aid in reducing both disability and healthcare utilization among these individuals.

Telemedicine-supported exercise programs have also a potential to address the economic and geographic barriers to access guideline-concordant care. Delamater et al found that fifty million adults reside more than 90 min from the nearest care facility. Access to cancer rehabilitation services is certainly influenced by geography; however, numerous additional factors may limit access to best available care, including sociodemographic status, health insurance and resource availability. Potential alternative strategies to address the transportation challenges for HSCT patients residing in remote location include implementation of telemedicine systems for home-based care delivery.<sup>25</sup> Overall, physical exercise delivered via telemedicine provided numerous benefits for HSCT patients, including enhancing both physical and emotional recovery after transplant therapy and potentially speeding up their return to optimal health and functional capacity following HSCT.<sup>24</sup> Future approaches for telemedicine-supported exercise in HSCT patients should be enhanced by the recent advances in machine learning optimization of individualized exercise plans,<sup>29,30</sup> predictive analytics utilizing patient-generated data,<sup>31,32</sup> and interfaces with electronic health records to support personalization,<sup>33,34</sup> adherence, efficacy, and safety of the home-based exercise programs.<sup>35,36</sup> Patient engagement in exercise programs can be facilitated by exergaming in virtual reality<sup>37,38</sup> and artificial intelligence-based chatbots<sup>39,40</sup> promoting patient education<sup>41,42</sup> and healthy behaviors.<sup>43,44</sup>

## Limitations

This review presented some limitations. The included studies were relatively few and predominantly pilot or feasibility trials, limiting the strength of the conclusions and their generalizability. Many studies lacked robust sample sizes and long-term follow-up data, and outcome measures varied considerably across the literature. Additionally, the majority of studies were conducted in high-income countries, which may not reflect global healthcare contexts or resource constraints. Such factors underscore the need for more geographically diverse, large-scale, and standardized research efforts to fully establish the efficacy, cost-effectiveness, and global applicability of telemedicine-based exercise interventions for HSCT patients residing in urban and rural areas. Limited information is available on differences in responses to the telemedicine-supported exercise interventions in patients receiving autologous or allogeneic stem cell transplantation. The impact of telemedicine-supported exercise interventions in patients with GVHD as compared to patients without GVHD has not been systematically studied. Another limitation is that this review did not conduct a formal risk of bias assessment for the included studies. While this could have provided a more thorough evaluation of the methodological rigor of the evidence, this limitation is mitigated by the fact that only peer-reviewed articles and experimental designs were included. These criteria inherently ensure a higher level of methodological quality and reduce the likelihood of significant bias within the included studies.

## Conclusions

Telemedicine for patients pre-, post- and during HSCT demonstrated to be feasible, beneficial, acceptable and effective with improvements in quality of life and physical function. However, the evidence base remains limited by small sample sizes, short follow-up periods, and predominantly feasibility-focused designs. Future research should emphasize larger, methodologically robust trials, consistent outcome measures, and include both urban and rural settings in order to establish best practices and guide broader implementation.

## Acknowledgments

We would like to express our gratitude to David Villarreal-Zegarra for his invaluable support in managing the Rayyan platform, which facilitated the screening of titles, abstracts, and full-text articles. We also extend our thanks to Stefan

Escobar-Agreda for his contributions as a reviewer during the screening and selection process. Their assistance was instrumental in the successful completion of this study.

## Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

## Funding

This study has been in part supported by the contract HT9425-24-1-0264 from the Congressionally Directed Medical Research Program.

## Disclosure

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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