

Pretransplant predictors of one-year bone mineral density change after allogeneic stem cell transplantation in Colombian adults

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Abstract

Purpose

Hematopoietic stem cell transplantation (HSCT) has improved long-term survival; however, it is associated with complications, including disturbances in bone metabolism. This study aimed to identify pre-transplant factors associated with changes in bone mineral density (BMD) in adults undergoing allogeneic HSCT (a-HSCT).

Methods

Retrospective cohort study, of 48 patients who underwent a-HSCT between 2009 and 2022. BMD was measured at the lumbar spine (LS) and femoral neck (FN) prior to transplantation and one year after the procedure. Simple linear regression analyses were performed for each independent variable and change in BMD, followed by multiple linear regression including variables with $p < 0.2$ in univariate analysis.

Results

At one year, BMD decreased by 4.7% at the LS and 9.8% at the FN ($p < 0.05$). The incidence of FN osteoporosis increased from 2 to 14 patients compared with baseline ($p < 0.001$), and three fractures were recorded. Prednisolone exposure was the strongest predictor of BMD loss ($R^2=0.19$; $p = 0.003$), exceeding the contribution of diabetes and pre-transplant relapse. For each gram of prednisolone administered, FN BMD decreased by 0.9%. The model explained 19% of the variance, suggesting that additional factors such as immune reconstitution, immobility, and nutritional status may also influence bone outcomes.

Conclusion

Bone loss during the first year after a-HSCT is frequent and clinically relevant. Cumulative glucocorticoid exposure appears to be a determinant of this process, supporting the need for early risk identification and preventive strategies to preserve bone health in this population.

INTRODUCTION

Allogeneic hematopoietic stem cell transplantation (a-HSCT) is an established therapeutic strategy for malignant and non-malignant hematologic diseases and has significantly improved patient survival [1]. However, despite these advances, a-HSCT remains associated with several long-term complications, including alterations in bone metabolism that may result in reduced bone mineral density (BMD), osteoporosis, and fractures [2, 3].

Bone loss after a-HSCT is a multifactorial process. Inflammatory mechanisms mediated by cytokines such as TNF- α and IFN- γ , together with dysregulation of signaling pathways including NF- κ B and osteoprotegerin, promote osteoclast activation and increased bone resorption [2, 3]. In addition, clinical factors such as graft-versus-host disease (GvHD) and its treatment further contribute to bone deterioration.

GvHD is one of the most frequent complications after a-HSCT, with reported incidences of approximately 55–56% for acute forms and 30–60% for chronic forms [4, 5]. Its management commonly involves prolonged use of immunosuppressive therapies, particularly glucocorticoids and calcineurin inhibitors, both of which are associated with impaired bone quality and an increased risk of osteoporosis [6–8]. Moreover, gastrointestinal involvement may compromise nutrient absorption, leading to deficiencies in calcium and vitamin D that further affect bone health [6]. Pretransplant BMD and vitamin D assessment is important to prevent bone loss within the first year [9]. In this context, vitamin D status has also been associated with post-transplant outcomes and healthcare burden, suggesting its role as a potentially modifiable factor in HSCT survivorship [10].

Similarly, these patients may exhibit physical deconditioning, characterized by reduced muscle strength and functional capacity, reflecting their state of clinical vulnerability [11]. In addition, they often experience other complications associated with a high symptom burden, leading to a deterioration in post-transplant quality of life [12].

After a-HSCT, BMD decreases by approximately 4.2% at the hip within the first year, with smaller changes at the forearm and lumbar spine (LS), and incidences of 10.6% non-traumatic fractures and 9.6% avascular necrosis, negatively impacting quality of life and prognosis[13]. Therefore, recognizing factors such as vitamin D deficiency, low calcium intake, immobility, thyroid dysfunction, chronic corticosteroid use, and hypogonadism is crucial to prevent bone complications [14].

In Colombia, some centers performing a-HSCT have established protocols to assess bone involvement after transplantation; however, local data evaluating the impact of this procedure on our population remain limited. Therefore, the aim of this study was to identify the pre-transplant clinical and paraclinical factors associated with these changes in Bucaramanga, Colombia.

METHODS

Design and study participants

Retrospective cohort study of 123 patients aged ≥ 18 years who underwent a-HSCT between 2009 and 2022 at the Fundación Oftalmológica de Santander–FOSCAL. Patients with pre-transplant osteosynthesis material or who died during the follow-up period were excluded. The final analysis included 48 patients with BMD assessments at the LS and femoral neck (FN), both pre-transplant and between 9 and 15 months post-transplant.

Sociodemographic, clinical, history, avascular necrosis, presence of hypogonadism, paraclinical (Serum 25-hydroxyvitamin D (25(OH)D), serum calcium, TSH) and imaging variables (T-score and Z score of LS and FN pre and one-year post-transplant, LS BMD and FN level pre and post-transplant, LS fracture pre and post-transplant, post-transplant hip fracture) were collected.

Outcomes

The primary outcome of the study was to assess changes in bone mineral density at the LS and FN one year after transplantation. The secondary outcome was to determine the prevalence of osteoporosis (T-score < -2.5) or low bone mass (Z-score < -2.0) based on bone densitometry. Additionally, the prevalence of fractures one year after transplantation was assessed.

Statistical analysis

A descriptive univariate analysis of the discrete and continuous variables was performed. Discrete variables were described using absolute and relative frequencies (percentage, %). Continuous variables were first assessed for normality using the Shapiro–Wilk test. Continuous variables with normal distribution were described using the estimation of means and standard deviation (SD), and continuous variables without normal distribution were described using medians and interquartile range (IQR).

To estimate osteoporosis or low bone mass prevalence and incidence in the study population, a new composite variable called "osteoporosis/low bone mass" was created, which included a T score < -2.5 (indicator of osteoporosis) or a Z score < -2.0 (indicator of low bone mass), both for the LS and the FN, because in the bone densitometry examination one or the other variable was available depending on the age of the person or the decision of the radiologist's reading.

The prevalence of the composite outcome at the LS and the FN level was also established separately and together, expressed as proportions. A chi-square test was then performed to establish the difference in proportions at 1 year. The incidence of the composite outcome was established by excluding people who had the composite outcome in the pre-transplant period and observing the proportion of this outcome post-transplant.

Subsequently, a bivariate analysis was performed using simple linear regression for each independent variable and the BMD difference of the LS and FN. Those variables that had a significance level of $p < 0.2$ in the simple linear regression model were included in a multiple linear regression to determine which variables best explain the BMD change. These analyses were performed in the STATA V15 statistical program.

Ethical considerations

Approved study by the institutional ethics committee (approval No. 08427/2023). This research was conducted ethically and was considered risk-free.

RESULTS

A total of 123 patients underwent allogeneic transplantation during the study period. Of these, 75 (60.9%) were excluded: 52 did not have BMD assessment at one year, 22 died before follow-up, and one was excluded for being a minor. Consequently, 48 patients (39.0%) were included in the analysis

The majority of participants were male (60.4%), with a mean age of 40.6 years (SD 14). Most patients (72.3%) had preserved functional status according to the Karnofsky Performance Score. Eight participants (16.7%) had type 2 diabetes (T2DM), and the median glomerular filtration rate was 110 mL/min. Acute lymphoid and myeloid leukemia were the primary diagnoses in 83.3% of cases. Pre-transplant laboratory tests showed insufficient vitamin D levels on average (Table 1).

Regarding post-transplant complications, 10 patients did not develop aGvHD and therefore did not receive corticosteroids. Among the remaining 38 patients, 70.8% developed aGvHD and 60.4% developed cGvHD. The median cumulative glucocorticoid dose was 3.65 g/year of prednisolone (IQR: 0–7.04 g). Additionally, 64% of patients had gastrointestinal GvHD (mostly mild), and 60.4% had cutaneous GvHD (mostly moderate). Table 1.

At the FN, the proportion of osteoporosis/low bone mass increased from 4.1% pre-transplant to 29.2% post-transplant ($p < 0.005$). No significant differences were observed at the LS or in the combined LS and FN analysis. The incidence of osteoporosis/low bone mass was 27.1% at the femoral neck and 16.7% at the LS. Three fractures were recorded after transplantation (**Online Resource 1**).

After transplantation, BMD decreased by 4.7% at the LS and 9.8% at the FN. These changes were accompanied by reductions in T-score and Z-score, more pronounced at the femoral site (Table 2).

In univariate analysis, glucocorticoid exposure was significantly associated with BMD loss at the femoral neck ($B = -0.0086$; 95% CI -0.014 to -0.0025 ; $p = 0.007$), whereas no significant associations were observed at the lumbar spine (Table 3–4).

In multivariable analysis, no independent predictors were identified for LS BMD change. In contrast, for FN BMD, cumulative prednisolone dose remained independently associated with BMD loss ($B = -0.0087$; $p = 0.014$), and the final model, which included cumulative prednisolone dose, T2DM, and pre-transplant relapse, explained 19% of the variance (**Table 5**). The inclusion of additional variables did not meaningfully improve model performance.

Figure 1 illustrates the inverse relationship between cumulative glucocorticoid dose and femoral neck BMD. For each 1 g increase in prednisolone dose, BMD decreased by approximately 0.9%, indicating a dose–response pattern.

DISCUSSION

In this Colombian retrospective cohort study of 48 individuals who underwent a-HSCT the reduced BMD was observed one year after transplantation, since the bone densitometry report was given as a T score or Z score, a composite variable was established to refer to osteoporosis or low bone mass depending on whether it was a T score <-2.5 or Z score <-2.0 . Prior to transplantation, the prevalence of this composite outcome was high in the lumbar spine at 22.9%, while it was lower in the FN at 4.1%. After one-year post-transplantation, the proportion of individuals with compromised bone density in the lumbar spine increased to 31.3%. Additionally, there was a statistically significant rise in the FN prevalence, which reached 29% ($p < 0.005$).

The incidence of osteoporosis or low bone mass was found to be 27.8% at the FN and 16% at the lumbar spine. During the study, there were 2 fractures (4%) in the lumbar spine and 1 fracture in the FN. At the 1-year follow-up, a loss of BMD was observed: 4.7% in the lumbar spine and 9.8% in the FN.

Our findings are consistent with those reported in previously published cohort studies. Stern's 2001 study documented a 4.2% loss of bone mass at the hip one year after allo-HSCT [13]. Similarly, Kashyap reported a 2% decrease in bone mass at L1–L4 vertebrae, along with a statistically significant 9% loss at the FN [15]. In Lee's 2004 study a 4.8% reduction in LS BMD and a 12.3% reduction at the FN were observed after one year [16]. Regarding fracture incidence, Baumgartner's 2019 study reported an overall rate of 5%, with an annual incidence of 1.6% [17]. Stern also documented a 10.6% incidence of atraumatic fractures within one year of transplantation [13]. Concerning osteoporosis, Baumgartner found that 13.8% of participants were affected at one year [17], while Pirls reported a prevalence of 17% [1]. Finally, a recent systematic review estimated that up to 14.2% of post-hematopoietic transplant patients develop osteoporosis and nearly 48% experience decreased BMD, underscoring the global magnitude of this complication [18].

Risk factors associated with impaired BMD documented in previous studies include vitamin D deficiency, hyperthyroidism, exposure to immunosuppressive agents, GvHD, cumulative corticosteroid dose, low body weight, malnutrition, thrombocytosis, and physical inactivity; these findings were reported in the study by Baumgartner [17]. Our results are consistent with those of other previously published cohort studies. Stern's 2001 study documented a 4.2% loss of bone mass at the hip one year after aHSCT [13]. Similarly, Kashyap reported a 2% reduction in bone mass at L1–L4 vertebrae, along with a statistically significant 9% loss at the FN [15].

In Lee's 2004 study, a 4.8% decrease in LS BMD and a 12.3% decrease at the FN were observed after one year [16]. The considerable variability in reported prevalence and incidence worldwide as evidenced by the high heterogeneity, with I^2 values ranging from 81% to 99% underscores the importance of studying population-specific cohorts [18]. This heterogeneity suggests that intrinsic population factors such as geographic origin, differences in conditioning regimens, baseline vitamin D status, and access to supplementation significantly influence outcomes.

With regard to fracture incidence, Baumgartner's 2019 study reported an overall rate of 5%, with an annual incidence of 1.6% [17]. Stern study also documented a 10.6% incidence of atraumatic fractures one year after transplantation [13]. Concerning osteoporosis, Baumgartner found that 13.8% of participants were affected at one year, while Pirls reported a prevalence of 17% [1, 17].

To identify variables associated with changes in BMD before and after one year of aHSCT in our study, we performed a simple linear regression analysis. At the LS level, no significant associations were found. However, at the FN, each additional gram of cumulative prednisolone dose was associated with a 0.9% reduction in BMD. This finding is consistent with the evidence that prolonged corticosteroid use remains the mainstay of first-line therapy for cGvHD but is accompanied by adverse effects such as osteoporosis and myopathy, underscoring the need for strategies that mitigate its impact on post-transplant bone health [19].

Subsequently, in the multiple linear regression analyses at the FN, the best-performing model included glucocorticoid dose, DM, and pre-transplant relapse as covariates. This model accounted for 19% of the variation in BMD. Although corticosteroid dose was independently and significantly associated with decreased FN BMD, it explained only a limited proportion of the observed variability. This finding suggests that bone loss after a-HSCT is a multifactorial process that cannot be fully explained by glucocorticoid exposure alone, indicating that additional factors such as immune reconstitution, nutritional status, physical inactivity, and other transplant-related or patient-specific determinants may also play an important role.

The identification of cumulative glucocorticoid dose as an independent risk factor for significant BMD loss underscores the importance of early recognition of the most vulnerable patients in clinical practice. This group particularly includes those with pre-existing cortical compromise, a history of DM, or pre-transplant relapse, in whom the implementation of preventive strategies aimed at preserving bone health should be considered. Among these, the timely initiation of antiresorptive therapy could benefit high-risk patients exposed to elevated glucocorticoid doses once the acute disease phase has resolved and clinical stability has been achieved. Nevertheless, it must be noted that these patients are often among the most fragile and frequently require polypharmacy, which may limit the feasibility of antiresorptive use during the early post-transplant period.

The strengths of this study lie in the establishment of a dedicated research cohort developed by a multidisciplinary team within an internationally recognized institution with extensive expertise in HSCT. Laboratory testing and imaging studies were performed in a reference laboratory that adheres to established quality standards. Furthermore, the use of multivariable linear regression analysis allowed for the identification of variables independently associated with the outcome, thereby minimizing bias in the results. Finally, the documentation of a dose-response effect, expressed as the percentage reduction in BMD per gram of prednisolone administered, translates a clinical observation into a quantifiable parameter directly applicable to clinical practice.

However, this study has several limitations related to its retrospective design, which increases the likelihood of information bias, susceptibility to confounding, and the potential influence of unmeasured variables. The absence of bone densitometry data also raises concerns regarding type 2 errors in the multivariable analysis, largely due to the limited sample size.

An additional important limitation is the lack of detailed information on the conditioning regimens administered prior to transplantation. Pre-transplant conditioning therapies, including chemotherapy and total body irradiation, are known to adversely affect bone metabolism and may contribute to early reductions in BMD [20–22]. In the absence of these data, it is not possible to determine the extent to which bone loss is attributable to pre-transplant conditioning as opposed to post-transplant immunosuppressive treatment. Future research should aim to systematically collect and analyze conditioning-related variables to more accurately assess their independent impact on post-transplant bone health.

In conclusion, the findings from this Colombian study, consistent with prior research, underscore the importance of assessing BMD in all patients before and after aHSCT. This is particularly relevant given that glucocorticoid dose was identified as an independent risk factor associated with significant changes in BMD. These results highlight the need to implement strategies aimed at preserving bone health in aHSCT recipients, especially among those exposed to glucocorticoids.

Declarations

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Authors contribution

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All authors have read and approved the final version of the manuscript.

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Conflict of Interest Disclosure: The authors declare that they have no conflicts of interest relevant to this work.

Ethics Approval: This study was conducted in accordance with the Declaration of Helsinki and Colombian research regulations (Resolution 8430/1993). Approval was obtained from the Institutional Ethics Committee (Approval No. 08427/2023).

Informed Consent: Due to the retrospective design and the use of anonymized data, the requirement for informed consent was waived by the ethics committee.

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Tables

Tables are available in the Supplementary Files section.

Figures

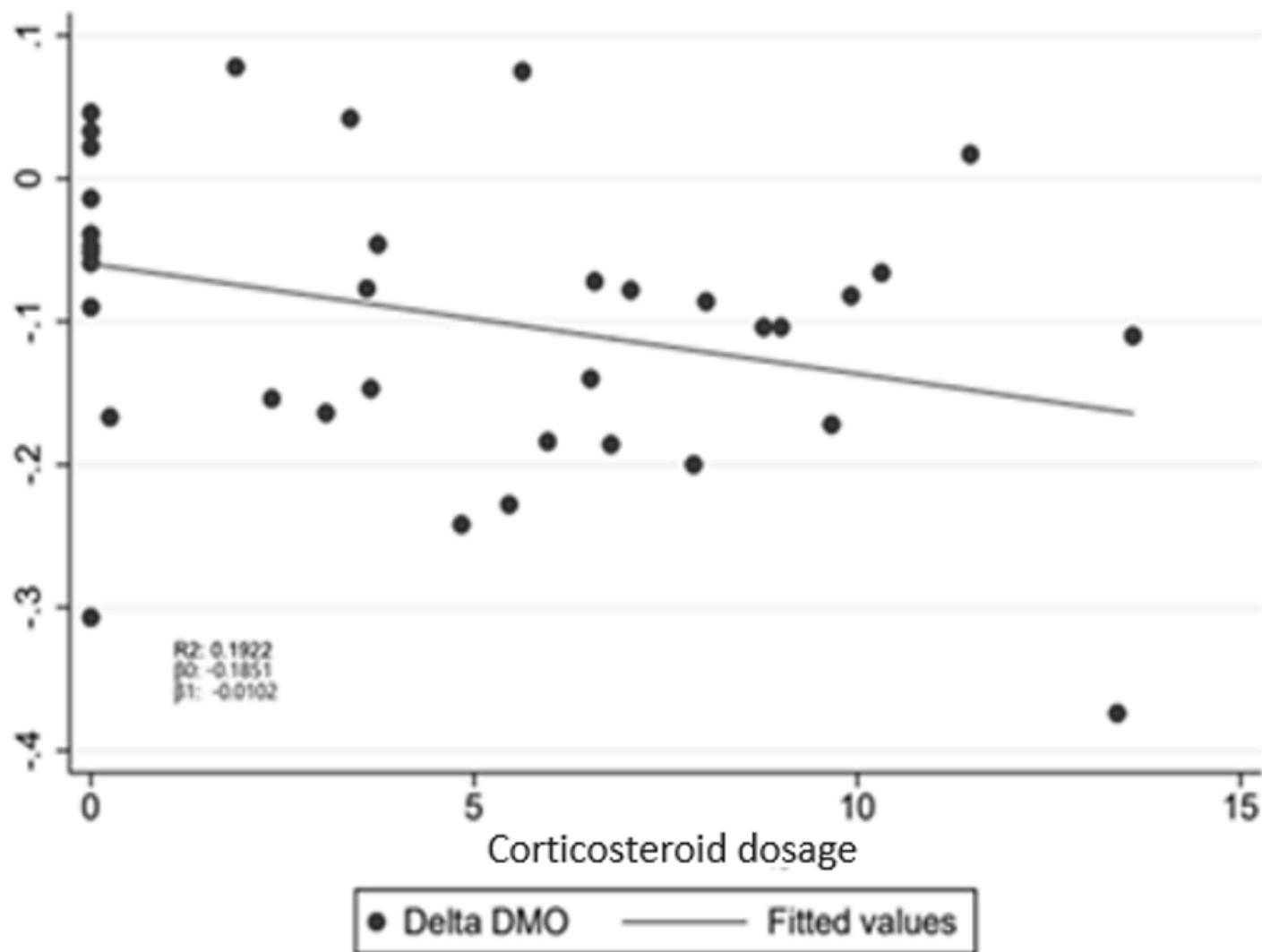


Figure 1

Glucocorticoid dose and bone mineral density

Supplementary Files

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