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ORIGINAL ARTICLE

Chronic hypoparathyroidism is associated with increased cortical bone density evaluated using high-resolution peripheral quantitative computed tomography

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Abstract

Purpose This cross-sectional study aimed to assess bone mineral density (BMD), bone microarchitecture and fracture prevalence in women with chronic postsurgical hypoparathyroidism (hypoPT).

Methods Twenty-seven women with postsurgical hypoPT and 44 age-matched healthy women were included. Dual-energy X-ray absorptiometry was used to evaluate areal BMD and vertebral fracture assessment. High-resolution peripheral quantitative computed tomography assessed microarchitecture and volumetric BMD at the distal radius and tibia. Biochemical parameters, including fibroblast growth factor 23, C-terminal cross-linking telopeptide of type I collagen (ICTP), and procollagen type I N-terminal propeptide (P1NP), were also measured. Previous low-impact fractures were assessed and the 10-year fracture risk was estimated using the FRAX tool for the Brazilian population.

Results No participant had prevalent clinical fractures, and both groups showed low risk for major and hip based on FRAX tool, but two hypoPT patients had moderate to severe morphometric vertebral fractures. Women with hypoPT had increased aBMD in the lumbar spine, femoral neck and total hip ($p < 0.05$) and higher cortical vBMD in the radius ($p = 0.020$) and tibia ($p < 0.001$). Trabecular bone was not affected. Both P1NP and ICTP suggested low bone turnover rates, but no significant correlation was observed between bone density or microstructure and any of the biochemical parameters.

Conclusions The prevalence of fragility fractures was low in HypoPT women and compatible with low fracture risk estimated by the FRAX tool. Patients had a higher aBMD and cortical vBMD than those of healthy control women, but the association with decreased bone turnover remains unclear.

Keywords Hypoparathyroidism · Bone mineral density · High-resolution peripheral quantitative computed tomography · Bone microarchitecture · Fracture risk

Introduction

Hypoparathyroidism (hypoPT) is a rare endocrine disease characterized by the absence or insufficiency of parathyroid hormone (PTH), with consequent hypocalcemia and hyperphosphatemia [1]. Anterior neck surgery is the most common cause of acquired hypoPT, accounting for approximately 75% of cases and is observed more frequently in older adult women [2]. Chronic PTH deficiency results in low bone turnover and increased bone mass [3]. A few studies, using dual-energy X-ray absorptiometry (DXA), have shown increased bone mineral density (BMD) in patients with hypoPT compared to individuals matched for age and sex [4–7].

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High-resolution peripheral quantitative computed tomography (HR-pQCT) is a noninvasive technique that provides a more detailed analysis of bone geometry and microarchitecture. A few studies have evaluated bone volumetric density and bone microstructure in patients with hypoPT. Cusano et al. showed an increase in cortical density at the radius and tibia in 60 patients with hypoPT. On the other hand, the same authors described a reduction in cortical density at the radius and tibia in patients with hypoPT at baseline compared to controls [8]. Three HRpQCT studies also demonstrated an increase in trabecular number and a reduction in trabecular separation, especially in nonsurgical patients with hypoPT [4, 8, 9].

The association of increased bone mass with an improvement in bone strength, which could result in reduced fracture risk, remains unknown. However, low bone turnover can lead to hypermature bone, which is unable to repair microfractures and is, therefore, more susceptible to fractures. Although increased cortical and trabecular masses have been described, it remains unknown whether these changes provide bone protection against fracture risk [10]. Studies assessing the fracture risk in hypoPT are rare, and available studies show contradictory results [10–18].

This study mainly aimed to evaluate bone density and microarchitecture using HRpQCT in patients with postsurgical hypoPT. Laboratory parameters, vertebral fracture prevalence, and 10-year fracture probability were also assessed using the FRAX tool.

Materials and methods

Participants

The study protocol was approved by the Research Ethics Committee of Hospital Universitario Clementino Fraga Filho (HUCFF – Universidade Federal do Rio de Janeiro, Brazil). Informed consent was obtained from all patients and controls before participation in the study, which was conducted in accordance with the Declaration of Helsinki. Patients were selected from the outpatient clinics for osteometabolic diseases at HUCFF and Hospital Federal de Bonsucesso (HFB) based on a medical history compatible with permanent hypoPT. Participants with other preexisting bone diseases, parathyroidectomy due to previous hyperparathyroidism, or use of medications that may interfere with bone health, such as glucocorticoids, bisphosphonates, denosumab, teriparatide, and chemotherapy, were excluded. Twenty-seven women with postsurgical hypoPT were selected and compared to 44 control women matched for age, body mass index (BMI), and menopausal status. The participants selected for comparison with patients with hypoPT had previously participated as a control group in other studies at the Osteometabolic Disease Research Center. They were healthy adults and their routine laboratory tests showed normal results. They also referred no previous low-impact fracture, past or current disease, or use of medications that affect bone metabolism. In addition, they were evaluated by DXAand HR-pQCT.

Laboratory analysis

Laboratory analyses included measurement of serum calcium, phosphorus, magnesium, and creatinine levels using routine methods as well as 24-hour urinary calcium and phosphorus excretion. Tubular reabsorption of phosphate (TRP; normal range >85%) was calculated using the following equation: $100 - [(Pu/Cru)/(Ps/Crs)] \times 100$, where Pu is urinary phosphorus; Cru, urinary creatinine; Ps, serum phosphorus; Crs, serum creatinine. The protein equivalent of nitrogen appearance (PNA) was calculated as follows: $[(\text{urinary urea} \times 0.46) + 2] \times (6.25/\text{weight})$ [19]. The glomerular filtration rate (GFR) was estimated using the Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) equation [20]. PTH was measured using chemiluminescence (Immulite 2000, Siemens, California, USA; normal range 11–67 pg/ml), whereas 25-hydroxyvitamin D was measured using electrochemiluminescence (Elecsys 2010, Roche, Berlin, Germany; normal range 30–100 ng/ml). Intact fibroblast growth factor 23 (iFGF23), procollagen type I N-terminal propeptide (P1NP), and C-terminal crosslinking telopeptide of type I collagen (ICTP) were measured using an enzyme-linked immunosorbent assay (ELISA) (USCN Life Science Inc., Wuhan, China). As these commercial kits do not provide reference ranges, we considered published data of control patients (mostly women of a similar age range as the hypoPT group) [21–23]. Table 1 shows the reported normal ranges of fibroblast growth factor 23 (FGF23), ICTP, and PINP levels.

Blood samples were collected after an overnight fast between 8 AM and 10 AM and stored at −80 °C. Dual-energy day, DXA, and HR-pQCT were performed on the day of the blood collection. The control group also underwent routine laboratory blood tests, including determining the levels of glucose, creatinine, calcium, phosphorus, thyroid-stimulating hormone (TSH), and PTH. FGF23 and bone turnover markers were not measured in the control group.

Fracture evaluation

Previous clinical fractures were ascertained using questionnaires and review of medical records. Only patients with low-trauma fractures were included. We also actively searched for morphometric vertebral fractures (VFs) using

Table 1 Characteristics of the hypoparathyroid patients

	Normal range	Results
Duration of hypoparathyroidism (years)	N/A	8.0 (6.0; 12.0)
Total supplemental calcium intake (mg/day)	N/A	2483.3 ± 1170.8
Calcitriol supplements (μg/day)	N/A	0.5 (0.3; 1.0)
Cholecalciferol dose (IU/day)	N/A	800.0 (0; 16000)
Ca (mg/dL)	8.5–10.2	8.0 ± 0.8
Pi (mg/dL)	2.5–4.5	5.1 ± 1.1
Mg (mg/dL)	1.8–2.6	1.9 ± 0.2
PTH (pg/mL)	11–67	4.0 (2.0; 15.1)
25(OH)D (ng/mL)	30–100	38.5 (30.6; 82.1)
FGF 23 (pg/mL)	26.2 ± 18.2	35.1 ± 14.7
P1NP (ng/mL)	42.3 ± 3.6	36.1 ± 15.7
ICTP (ng/mL)	2.9 ± 1.8	0.07 ± 0.05
TSH (μUI/mL)	0.40–4.00	1.81 (0.77; 5.60)
FT4 (ng/dL)	0.89–1.76	1.36 (1.05;1.53)
GFR CKD-EPI (mL/min/1.73 m^2)	≥90	76.9 ± 26.8
24-Hour urinary calcium excretion (mg/24 h)	20–250	85.4 (69.3; 189.7)
24-Hour urinary phosphorus excretion (mg/24 h)	340–1000	543.2 ± 191.9
TRP (%)	>85	90.7 ± 4.0
PNA (g/kg/24 h)	0.8–1.2	0.5 (0.4; 0.5)

Data are presented as the mean ± SD, median (25^{th} and 75^{th}) or *n* (%)

BMI Body Mass Index, *Ca* serum calcium, *Pi* serum phosphorus, *Mg* serum magnesium, *PTH* parathyroid hormone, *25(OH)D* 25-hydroxyvitamin D, *FGF 23* fibroblast growth factor 23, *P1NP* N-terminal propeptide of type I procollagen, *ICTP* C-terminal crosslinking telopeptide of type I collagen generated by matrix metalloproteinases, *TSH* thyroid-stimulating hormone, *FT4* serum free thyroxine 4, *GFR CKD-EPI* Glomerular filtration rate estimated by CKD-EPI, *TRP* tubular reabsorption of phosphate, *PNA* protein equivalent of nitrogen appearance

vertebral fracture assessments (VFA) made during DXA examinations. Using Genant's semiquantitative methodology, VFs were classified as moderate or grade 2 (25–40% loss of spinal height) and severe or grade 3 (more than 40% loss of spinal height). Mild VFs or grade 1 fractures (20–25% reduction in spinal height) were not considered [24, 25]. Vertebrae from T7 to L4 were included in the analysis. The fracture risk assessment tool available on the FRAX Brazil tool website (https://abrasso.org.br/calculadora/calculadora/) was used to manually enter the data, including BMD, and calculate the 10-year probability of hip and major fractures. Using the output from the FRAX calculator, the intervention thresholds for high and low fracture risk were determined using the National Osteoporosis Guidelines Group methodology adapted for the Brazilian population [26].

Areal bone density evaluation using DXA

All participants underwent DXA using Prodigy-GE equipment (GE Lunar Prodigy Advance, GE Healthcare, Madison, WI, USA) at the HUCFF to assess areal BMD at the lumbar spineLS), femoral neck (FN), and total hip (TH). The results are expressed as absolute values (g/cm^2) and standard deviations (SDs) from the expected mean BMD for the reference age-matched population, Z-score, and T-score in postmenopausal women [27]. The BMD variability coefficients for the lumbar spine and hip were 1.5% and 2.3%, respectively.

HR-pQCT

Bone volumetric density and microarchitecture were measured on an appropriately immobilized nondominant distal forearm and tibia by HR-pQCT using X-treme CT I equipment (SCANCO Medical AG, Brüttisellen, Zurich, Switzerland). This system employs a 2D detector combined with a 0.08-mm point-focus X-ray tube, which enables the acquisition of 110 slices from each site with an 82-μm nominal resolution. The radiation dose was similar to that used in standard DXA procedures (less than 3 Sv per measurement). Attenuation data were transformed into equivalent hydroxyapatite (HA) densities. The images obtained from all participants were evaluated by the same professional. The variables included in the analysis were as follows: volumetric BMD (g HA/cm^3) in the trabecular (Tb.BMD), cortical (Ct.BMD), or entire bone (Tt.BMD); cortical thickness (Ct.Th, mm); trabecular bone fraction (BV/TV, %); trabecular thickness (Tb.Th, mm); trabecular number (Tb.N, mm^{-1}); trabecular separation (Tb.Sp, mm); and inhomogeneity network (Tb.1/N.SD, mm), which reflects the heterogeneity of the trabecular network [28–30].

Statistical analysis

All the statistical analysis was performed using SPSS version 24. The data are expressed as absolute numbers (%) for categorical variables, mean ± SD for continuous variables with a normal distribution, and median (25^{th} and 75^{th} percentiles) for continuous variables with a nonnormal distribution. The Kolmogorov–Smirnov test was used to evaluate the distribution patterns of continuous variables. Unpaired Student's *t* test or Mann–Whitney U test was performed to compare normal and non-normal independent groups, respectively. Pearson's r correlation coefficients or Spearman's RO were used for association analysis between two symmetric or asymmetric quantitative variables, respectively. Statistical significance was defined as a two-sided *p*-value of <0.05.

Table 2 Clinical characteristics and dual energy X-ray absorptiometry parameters of cases and controls

	Control ($n = 44$)	Hypoparathyroid ($n = 27$)	p value[b]
Age (years)	59.95 ± 9.39	56.3 ± 11.4	0.143
BMI (kg/m^2)	29.45 ± 4.73	32.27 ± 7.18	0.051
Menopausal status *N* (%)	34 (77)	21 (78)	0.846
Lumbar spine BMD (g/cm^2)	1.075 ± 0.176	1.248 ± 0.196	0.003
Lumbar spine Z-score	−0.2 ± 1.5	1.1 ± 1.6	0.009
Lumbar spine T-score[a]	−1.0 ± 1.4	0.4 ± 1.6	0.0002
Total hip BMD (g/cm^2)	0.967 ± 0.127	1.090 ± 0.112	<0.001
Total hip Z-score	0.3 ± 1.0	1.2 ± 1.1	<0.001
Total hip T-score[a]	−0.3 ± 1.0	0.7 ± 0.4	<0.0001
Femoral neck BMD (g/cm^2)	0.924 ± 0.120	1.064 ± 0.115	<0.001
Femoral neck Z-score	0.1 ± 0.8	1.0 ± 0.9	<0.001
Femoral neck T-score[a]	−0.8 ± 0.9	0.3 ± 0.6	<0.0001
Lowest Z-score	−0.6 ± 1.1	0.6 ± 1.1	<0.001
Lowest T-score[a]	−1.4 ± 1.1	−0.1 ± 1.1	<0.0001
FRAX Major with BMD (%)	2.9 ± 0.9	2.2 ± 0.6	0.006
FRAX Hip with BMD (%)	0.4 ± 0.5	0.2 ± 0.6	<0.0001
Patients classified as low risk FRAX-NOGG with BMD (%)	100	100	N/A

BMI Body Mass Index, *BMD* Bone mineral density, *FRAX* Fracture Risk Assessment Tool, *FRAX Major* 10-year probability of major osteoporotic fracture assessed by FRAX with BMD, *FRAX Hip* 10-year probability of hip fracture assessed by FRAX with BMD, *NOGG* The National Osteoporosis Guideline Group

[a]T-score only for postmenopausal women (controls and patients with HypoPT)

[b]T student test or Mann–Whitney test. Data are presented as the mean ±SD or median (25th and 75th)

Results

Baseline characteristics

The mean age of 27 female patients with hypoPT was 56.3 ± 11.4 years (78% women were at post-menopause stage). They had permanent postsurgical hypoPT and the most frequent indications for thyroidectomy were nontoxic multinodular goiter (59.2%) and thyroid cancer (33.4%). Two women (7%) had a prior diagnosis of Graves' disease. Nineteen (70%) patients had hypertension, seven (26%) had type 2 diabetes mellitus, three (11%) were current smokers, and no patient had history of alcohol consumption. All patients with hypoPT had normal GFR (at or above 60 mL/min/1.73 m^2) and their free T4 and TSH levels were maintained within normal limits. Table 1 shows other details regarding hypoPT and the biochemical features. The control group consisted of 44 healthy age-matched women (mean age 59.9 ± 9.4 years); the participants in the control group were selected using the same excluding criteria as those used for the hypoPT group.

Areal bone density

Table 2 presents the areal BMD, Z-scores, and T-scores. Patients with hypoPT showed higher BMD than those in the control group at all sites.

Volumetric bone density and microarchitecture

In both the radius and tibia, Ct. BMD was higher in patients with hypoPT than that in the control group. No significant differences were observed in the trabecular parameters between the two groups (Table 3). No correlation was found between laboratory data, including FGF23, ICTP, and P1NP levels, and densitometric and HR-pQCT parameters.

Laboratory data

In patients with hypoPT, the serum calcium level was close to the lower limit of the normal range, and the serum phosphorus level was above the reference range. The mean serum FGF23 level was 35.1 ± 14.7 pg/ml, which was higher than the reference range in healthy participants [21]. The mean serum levels of P1NP and ICTP were 36.1 ± 15.7 ng/ml and 0.07 ± 0.05, respectively, which were lower than the reference values [22, 23]. The 24-h urinary metabolic evaluation revealed low PNA and high-normal TRP levels despite hyperphosphatemia (Table 1). Blood test results were normal in the control group (data not shown). Biochemical data were not compared between groups due to differences in the methodology employed for vitamin D and PTH or due to the lack of information, as FGF23 and bone turnover markers were not measured in the control group.

Table 3 High-resolution peripheral quantitative computed tomography parameters

	Control ($n = 44$)	Hypoparathyroid ($n = 27$)	p value[a]
Radius			
Tt.BMD (mg HA/cm^3)	316.30 ± 73.81	336.97 ± 59.22	0.222
Tb.BMD (mg HA/cm^3)	144.22 ± 35.98	150.74 ± 42.60	0.492
Ct.BMD (mg HA/cm^3)	871.66 ± 80.68	913.30 ± 53.49	0.020
Ct.Th (mm)	0.74 ± 0.20	0.80 ± 0.18	0.216
Tb.N (1/mm)	1.86 ± 0.33	1.85 ± 0.38	0.870
Tb.Sp (mm)	0.49 ± 0.11	0.50 ± 0.13	0.828
Tb.Th (mm)	0.07 ± 0.01	0.07 ± 0.01	0.432
BV/TV (%)	0.12 ± 0.03	0.13 ± 0.04	0.489
Tb.1/N.SD (mm)	0.20 (0.17; 0.26)	0.19 (0.16; 0.26)	0.559
Tibia			
Tt.BMD (mgHA/cm^3)	283.67 ± 49.82	302.01 ± 48.53	0.154
Tb.BMD (mgHA/cm^3)	143.61 ± 30.00	143.93 ± 25.75	0.965
Ct.BMD (mgHA/cm^3)	868.03 ± 69.39	921.89 ± 44.95	0.001
Ct.Th (mm)	1.12 ± 0.25	1.21 ± 0.21	0.139
Tb.N (1/mm)	1.73 ± 0.38	1.64 ± 0.26	0.343
Tb.Sp (mm)	0.51 (0.44; 0.60)	0.51 (0.46; 0.62)	0.776
Tb.Th (mm)	0.07 ± 0.02	0.07 ± 0.01	0.445
BV/TV (%)	0.12 ± 0.02	0.12 ± 0.02	0.964
Tb.1/N.SD (mm)	0.24 (0.19; 0.28)	0.24 (0.22; 0.31)	0.568

Data are presented as the mean ±SD or median (25th and 75th)

HR-pQCT High resolution peripheral quantitative computed tomography, *Total.vBMD* Total volumetric bone mineral density, *Tb.BMD* Trabecular volumetric bone mineral density, *Ct. BMD* Cortical volumetric bone mineral density, *CtTh* Cortical thickness, *Tb.N* Trabecular number, *Tb.Sp* Trabecular separation, *Tb.Th* Trabecular thickness, *BV/TV* Trabecular bone fraction, *Tb.1/N.SD* Inhomogeneity of trabecular network

[a]T student test or Mann–Whitney test

Fractures and FRAX

None of the participants in both the groups had a history of prevalent fragility fractures. Morphometric VFs were only found in two patients with hypoPT. According to the Genant visual semi-quantitative technique, one patient had one severe (T5) and one moderate vertebral fracture (T6), and another patient presented with one moderate vertebral fracture at T8. Women with hypoPT had a lower estimated risk of major fractures and hip fractures compared with the control group based on the FRAX Brazil tool. All patients with hypoPT had a fracture probability assessment below the intervention limit according to the NOGG calculator; this was found to be identical to that of the control group (Table 2).

Discussion

Skeletal changes in patients with hypoPT are poorly understood. Here we describe higher areal and volumetric bone density, especially in the cortical compartment, which is possibly associated with low bone turnover in a women population with postsurgical hypoPT. The fracture risk evaluated by FRAX-NOGG was low when BMD was considered.

The increased areal BMD values (obtained using DXA) in the spine and hip were in accordance with the data described in other hypoPT cohorts [5–7, 31–35]. Elevated BMD has been documented in individuals with post-surgical, autoimmune, and idiopathic hypoparathyroidism subsequent to prolonged therapy with calcium and vitamin D [3]. In general, BMD increased at all skeletal sites, with the greatest T- or Z-scores observed in the lumbar spine. Although most of our patients were postmenopausal women, the mean BMD T-scores were equal to or higher than +1SD. These findings suggest that hypoPT protects against postmenopausal bone loss [3].

The higher Ct.BMD at both the radius and tibia in our patients, compared with control group, aligns with findings observed in a prior investigation that assessed bone microarchitecture [4]. Compared with the control group, participants with hypoPT had increased cortical density at the radius and tibia in all age and sex subgroups; our results are consistent to these findings. Other changes, such as trabecular parameters, were observed in a few subgroups; however, these patients were younger and premenopausal [4]. The same authors studied patients with hypoPT who showed lower cortical densities at the radius and tibia compared with control participants [8]. The apparent discrepancy in cortical bone data was justified by the differences in the control groups of both studies as the cortical bone parameters of patients with hypoPT were very similar to the previous study. In another study of patients with nonsurgical hypoPT, changes were mainly observed in trabecular bone as increased trabecular number at both the radius and tibia, and elevated cortical density was only observed at the tibia in postmenopausal women [9]. We did not find any significant changes in the trabecular parameters in patients with hypoPT compared with the control group on HR-pQCT. Although cortical bone density seems to be the main contributor to the increase in areal BMD, we cannot exclude the participation of the trabecular bone. As previous studies have shown an increase in trabecular parameters, especially in nonsurgical patients, these differences could be attributed to the fact that we evaluated only postsurgical patients and that there may be differences in bone quality between patients with surgical and nonsurgical hypoPT, as suggested by Liu et al. [4, 8, 9].

Data on fracture risk in patients with hypoPT are limited, and studies have shown controversial results. Fujiyama et al. studied women with postsurgical hypoPT, and the incidence of spinal deformity based on radiographic findings was three times lower in women with hypoPT than that in controls [12]. Mendonça et al. found increased morphometric VFs in postmenopausal postsurgical women with

hypoPT compared with healthy controls [13]. A cross-sectional study reported an increased incidence of morphometric vertebral fracture in patients with idiopathic hypoPT [14]. Two longitudinal population-based studies by Underbjerg et al. showed no difference in vertebral and overall fractures between participants with hypoPT and controls and reported that the risk for upper extremity fractures was lower in postsurgical patients and increased in nonsurgical hypoPT for unknown reasons [15, 16]. Vadiveloo et al. found no increased risk of fractures in patients with postsurgical or nonsurgical disease [17]. However, these studies did not evaluate vertebral imaging. Cipriani et al. studied postmenopausal women with postsurgical hypoPT and found an increased prevalence of VFs identified by VFA, mostlygrade 1, in the hypoPT group compared with the control group. The 10-year probability of fracture using the FRAX tool did not exceed the accepted threshold values in both groups [18]. Finally, a recent meta-analysis observed that patients with nonsurgical hypoPT have an almost 2-fold increased risk of VFs compared to surgical patients, with no difference in the risk of vertebral or any fracture in postsurgical hypoPT compared to controls [10]. In our study, the hypoPT patients had a low fracture risk calculated using the FRAX tool and NOGG calculator and no clinical fracture, but VFA identified moderate to severe VFs in two of them.

While the hypoPT group showed a tendency towards higher body weight (and BMI), this difference did not reach a statistically significant level. We cannot rule out the influence of the weight-bearing effect on increased BMD, mostly in the hip and distal tibia. However, the DXA and HR-pQCT bone parameters were not associated with BMI.

Increased serum FGF23 levels may be associated with hyperphosphatemia in hypoPT patients. We observed that even in the presence of higher levels of FGF23, patients had TPR > 90% [21]. Despite the fact that FGF23 is recognized as a phosphaturic hormone, this effect was not observed in the absence of PTH. Both PTH and FGF23 regulate phosphate excretion through their actions on sodium-phosphate co-transporters in the proximal tubule. However, the interactions between these phosphaturic hormones are not fully understood. Although FGF23 is one of the main regulators of urinary phosphate excretion, sufficient PTH is necessary for the full phosphaturic effect of FGF23 [31]. In a recent study, Ovejero et al. observed that in patients with hypoPT, the administration of hPTH 1–34 resulted in a significant but transient reduction in TRP and normalization of hyperphosphatemia, suggesting that FGF23 phosphaturic effect depends on the presence of PTH [36]. Rupp et al. observed that FGF23 levels were significantly correlated with trabecular bone microarchitecture, whereas no significant correlation was found with cortical bone parameters in patients with osteoporosis [37]. No significant correlation was observed between FGF23 levels and DXA or HR-pQCT bone parameters in our study. We also observed that circulating markers of bone formation (P1NP) and bone resorption (ICTP) were lower than normative previously published data [22, 23]. This finding is consistent with prior studies that demonstrated reduction of bone turnover biomarkers [38, 39].

The cross-sectional design and small sample size are limitations of our study. However, the rarity of hypoPT should be considered. Additionally, mild fractures were not included in our analysis; however, they were less relevant in predicting future fractures. The strength of our study is that it addresses a topic that has not been fully defined in the literature and provides data on bone microstructure in a group of Brazilian patients with hypoPT. Furthermore, few studies with heterogeneous results have assessed bone microstructure in postsurgical patients with hypoPT using morphometric fracture investigations, risk of fractures calculated using FRAX, and biochemical analysis of FGF23.

In summary, our study showed that patients with surgical hypoPT have elevated areal BMD at both the spine and hip and an increased cortical volumetric BMD. Changes in trabecular microstructure were not observed. Two patients had morphometric VFs, despite higher bone density and low fracture risk estimated by the FRAX tool. The correlation with compromised bone remodeling warrants further investigation.

Author contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by R.G.S.R., S.P., A.P., C.P.G., L.F.C.L., F.d.P.P.N., L.M.C.d.M., M.L.F.F. and M.M. The first draft of the manuscript was written by R.G.S.R., and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Compliance with ethical standards

Conflict of interest The authors declare no competing interests.

Ethical approval This study was performed in line with the principles of the Declaration of Helsinki. The study was approved by the Research Ethics Committee and registered at Plataforma Brazil (CAAE 93448618.4.0000.5257).

Informed consent Informed consent was obtained from all the individual participants included in the study.

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