

# Preoperative vitamin D deficiency is associated with increased risk of postoperative hypocalcemia after total thyroidectomy

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## ABSTRACT

Prior single-institution studies suggest that preoperative vitamin D deficiency (VDD) is associated with postoperative hypocalcemia and a prolonged length of hospital stay following total thyroidectomy. In this study, we employ a multi-institutional, de-identified electronic health records database to address this issue. We hypothesize that total thyroidectomy patients with preoperative VDD will be at an increased associated risk of postoperative hypocalcemia and hospitalization. Using Cerner Health Facts, we identified 2447 patients who underwent total or subtotal thyroidectomy between 2008 and 2016 and who had a documented 25-hydroxyvitamin D concentration obtained within 12 months of the surgery date using International Classification of Diseases 9/10, Current Procedural Terminology and Healthcare Common Procedure Coding System codes. Data from 984 patients who underwent total thyroidectomy were analyzed. Analysis of variance models estimated the effect of VDD on postoperative numerical variables. Multiple logistic regression estimated the risk of postoperative hypocalcemia and hospital stay, adjusting for any imbalanced demographic variables and operative characteristics. On average, postoperative total calcium concentrations in the VDD group were lower by 0.3 mg/dL compared with that of the non-VDD group ( $p < 0.01$ ). The risk of postoperative hypocalcemia was 2.2 times higher in the VDD group compared with the non-VDD group ( $p < 0.01$ ). Although the length of hospital stay after thyroidectomy was longer in the VDD group compared with the non-VDD group ( $p = 0.03$ ), VDD is not an independent risk factor for prolonged hospitalization following thyroidectomy ( $p = 0.13$ ). VDD is associated with a higher risk of hypocalcemia following total thyroidectomy. Prethyroidectomy operative screening for VDD should be considered.

## INTRODUCTION

Hypocalcemia is a commonly occurring postoperative complication following thyroidectomy<sup>1–4</sup> and is associated with other postoperative complications, such as delayed

## Significance of this study

### What is already known about this subject?

- ▶ Hypocalcemia is a common complication following total thyroidectomy.
- ▶ Vitamin D plays a critical role in calcium homeostasis.
- ▶ Findings from previous studies do not agree about the effect of preoperative vitamin D deficiency on the associated risk of postoperative hypocalcemia.

### What are the new findings?

- ▶ Using a large electronic health records database compiling over 9 years of data, we found the adjusted risk of postoperative hypocalcemia was 2.2 times greater in vitamin D-deficient patients undergoing total thyroidectomy compared with those who were not vitamin D-deficient ( $p < 0.01$ ).
- ▶ We also found that the adjusted risk of prolonged hospitalization following thyroidectomy was not higher in vitamin D-deficient patients compared with those who were not vitamin D-deficient ( $p = 0.11$ ).

### How might these results change the focus of research or clinical practice?

- ▶ We recommend that preoperative vitamin D concentrations be determined prior to the performance of total thyroidectomy and that consideration be given to preoperative vitamin D repletion in those who are deficient.

discharge after surgery, unexpected reoperation, and an increased rate of recurrent laryngeal nerve injury.<sup>5–7</sup> In a retrospective cross-sectional study, about 19.1% of 126,766 patients who underwent total thyroidectomy developed postoperative hypocalcemia within 30 days of surgery.<sup>8</sup> The spectrum of clinical manifestations of hypocalcemia varies from ectodermal and dental changes and cataracts in chronic hypocalcemia, to tetany, papilledema, and life-threatening seizures in acute hypocalcemia.<sup>9–13</sup> While the presentation of hypocalcemia is well characterized,

the threshold of serum calcium concentration used for the diagnosis of hypocalcemia may be loosely defined as varying from serum calcium concentration of <7.5 mg/dL to 8.4 mg/dL.<sup>14–16</sup>

Calcium homeostasis is maintained by the active form of vitamin D, 1,25-dihydroxyvitamin D (1,25(OH)<sub>2</sub>D), in the intestine, kidney and bone.<sup>17–20</sup> In the intestine, 1,25(OH)<sub>2</sub>D directly promotes intestinal calcium absorption.<sup>17</sup> In the kidney and bone, parathyroid hormone (PTH) plays a major role in restoring calcium homeostasis by increasing the production of 1,25(OH)<sub>2</sub>D, which subsequently acts to increase calcium reabsorption into the bloodstream.<sup>18–20</sup> As such, many research efforts have been made to study the association between vitamin D deficiency (VDD) and postoperative hypocalcemia after thyroidectomy.<sup>5 7 14 21–23</sup> It is difficult, however, to generalize the findings from such studies due to their relatively small sizes and regionally isolated sample selections. In this study, we aim to ascertain the effect of VDD (25-hydroxyvitamin D ≤20 ng/mL) on serum calcium concentrations and length of stay following total thyroidectomy using a large-scale, multi-institutional electronic health records database. We hypothesize that VDD in total thyroidectomy patients will be associated with decreased serum calcium concentration and increased length of hospital stay compared with that of patients without VDD.

## METHODS

### Settings

This is a retrospective observational study using a large-scale, multi-institutional, de-identified electronic health records database called Health Facts, which provides diagnostic and medical laboratory data from hundreds of participating clinics and hospitals that employ Cerner PowerChart electronic health records across the USA. Specifically, Health Facts contains de-identified data from more than 68 million unique patients from more than 600 hospitals and clinics across the USA. Using this database, all patients who underwent total or subtotal thyroidectomy between 2008 and 2016 (inclusive) were identified using International Classification of Diseases 9/10 codes (06.3, 06.39, 06.4, 06.5, 06.50, 06.51, 06.52, 06.8, 06.81, 06.89) and Current Procedural Terminology/Healthcare Common Procedure Coding System codes (60210–60225, 60260, 60240, 60271, 60252, 60254, 60270).

### Inclusion/Exclusion

Inclusion criteria were performance of total or subtotal thyroidectomy on adult patients (≥18 years) and a documented 25-hydroxyvitamin D concentration obtained within 12 months of the date of surgery. Exclusion criteria were performance of a partial thyroidectomy or parathyroidectomy or lack of a documented 25-hydroxyvitamin D concentration obtained within the 12-month window surrounding the surgery.

### Measurements

Patients included in the analysis were divided into two groups: a vitamin D-deficient (VDD) group and a non-vitamin D-deficient (non-VDD) group. The VDD group was defined by a 25-hydroxyvitamin D concentration ≤20 ng/

mL and the non-VDD group by a 25-hydroxyvitamin D concentration >20 ng/mL. In all cases, preoperative and postoperative laboratory measurements obtained closest to the surgery date were analyzed. Preoperative variables included patient demographics such as age and sex, indication for surgery, and preoperative laboratory measurements for 25-hydroxyvitamin D, serum calcium, phosphate, and albumin concentrations. Outcome variables included postoperative laboratory measurements such as serum calcium, albumin, phosphate, and PTH concentrations. The primary outcome variables (corrected serum calcium concentrations and length of hospital stay) were dichotomized into binary variables for analysis. Hypocalcemia was defined as a corrected serum calcium concentration <8 mg/dL. Hospitalization was defined as the absence of same-day discharge indicated by a length of hospital stay >0 days.

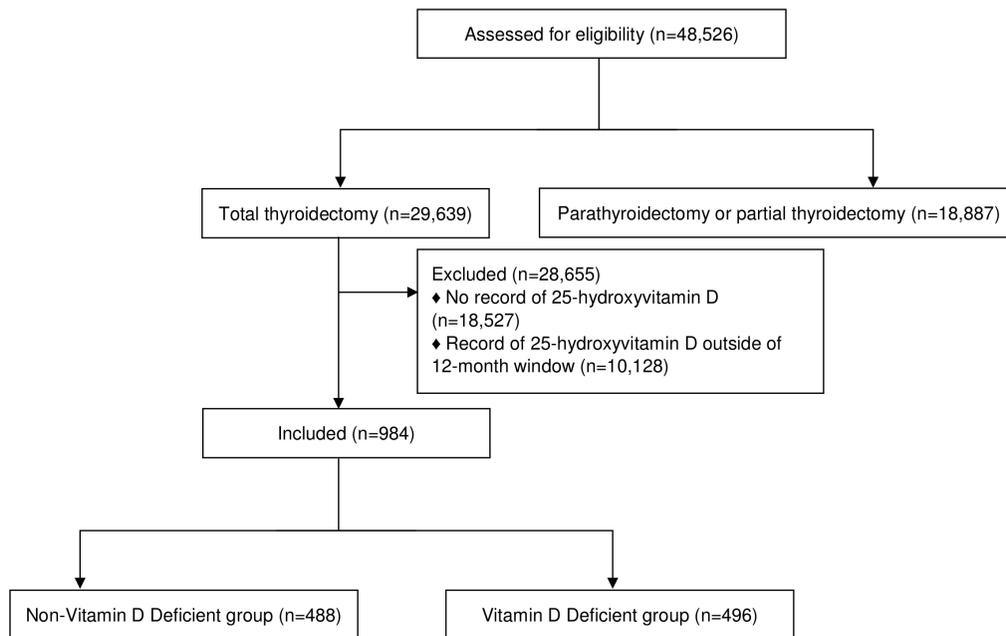
### Statistical analysis

For descriptive statistics,  $\chi^2$  tests or Fisher's exact tests were used to assess any association between preoperative and postoperative categorical variables, and two-sample t-tests were used to compare group means for preoperative numerical variables. For postoperative numerical variables displaying normal distribution, analysis of variance models estimated the effect of VDD in the VDD group compared with the non-VDD group. For postoperative variables displaying exponential distribution, a likelihood ratio test was used for mean comparison between groups. For the two dichotomized primary outcome variables, hypocalcemia and prolonged length of hospital stay, multiple logistic regression modeling estimated the risk of postoperative hypocalcemia and prolonged hospital stay, adjusting for any imbalanced demographic variables and operative characteristics. The imbalanced demographic variables (age, race, urban/rural status) were included in the logistic regression model to account for any confounding effect from these group differences. Since the performance of neck dissection is known to be associated with postoperative hypocalcemia,<sup>24</sup> performance of this procedure was also adjusted for in the logistic regression model to account for any potential effect on the primary outcome. Finally, a sensitivity analysis was conducted on patients with vitamin D measurements taken within 90 days of surgery to ascertain the effect of the inclusion time period on the estimates. All analyses were performed using SAS V9.4.

## RESULTS

### Sample selection

Figure 1 illustrates the sample selection. A total of 48,526 patients underwent total or partial thyroidectomy with or without concomitant parathyroidectomy within the predefined study interval. Of these, 18,887 patients who underwent parathyroidectomy or partial thyroidectomy were excluded. Of those who underwent total or subtotal thyroidectomy, 28,655 were excluded due to lack of a 25-hydroxyvitamin D level being obtained within the predefined 12-month window. Data from the remaining 984 patients were analyzed. As shown in table 1, there were 488 patients in the non-VDD group and 496 patients in the VDD group. There were 410 vitamin D measurements obtained preoperatively and 574 obtained postoperatively.



**Figure 1** Study flow chart.

### Preoperative characteristics

The average length of time between vitamin D measurement and surgery was  $15 \pm 169$  days in the VDD group compared with  $44 \pm 167$  days in the non-VDD group ( $p < 0.01$ ). The mean age in the VDD group was younger compared with the non-VDD group ( $p < 0.01$ ). As expected, the mean preoperative vitamin D concentration in the VDD group ( $9.6 \pm 8.3$  ng/mL) was significantly lower than that of the non-VDD group ( $32.6 \pm 12.0$  ng/mL,  $p < 0.01$ ). The mean preoperative serum calcium was also significantly lower in the VDD group ( $8.4 \pm 1.0$  mg/dL) compared with that of the non-VDD group ( $8.6 \pm 0.9$  mg/dL,  $p < 0.01$ ). Although Caucasians were most prevalent in both groups, there was a statistically significant difference in race and ethnicity between the two groups ( $p < 0.01$ ). Similarly, although most patients were from an urban setting as opposed to a rural setting in both groups, the VDD group showed a significantly higher proportion of patients from an urban setting compared with the non-VDD group ( $p = 0.03$ ). A higher rate of performance of neck dissection was observed in the non-VDD group compared with VDD group ( $p < 0.01$ ). Other demographic and clinical characteristics such as sex, body mass index, malignancy in surgical pathology, and season of surgery were also considered but did not show a statistically significant difference between the two groups.

### Postoperative characteristics

As shown in [table 2](#), postoperative total calcium concentration was significantly lower by 0.3 mg/mL, on average, compared with that of the non-VDD group ( $p < 0.01$ ). Same-day discharge was significantly higher in the non-VDD group compared with the VDD group ( $p = 0.03$ ), and the length of hospital stay after thyroidectomy was prolonged in the VDD group by 5 hours, on average, compared with the non-VDD group ( $p = 0.03$ ). The proportion of patients who were prescribed calcium and/or vitamin D supplemental therapy on discharge was significantly higher in the

non-VDD group compared with the VDD group ( $p < 0.01$ ). Postoperative serum magnesium concentration was slightly higher in the non-VDD group compared with the VDD group ( $p < 0.01$ ), and serum creatinine concentration was also significantly higher in the non-VDD group compared with the VDD group ( $p = 0.01$ ). Other postoperative variables such as ionized serum calcium concentration, serum phosphate concentration, and serum albumin concentration were analyzed and found to be similar between the two groups.

As shown in [table 3](#), multiple logistic regression modeling demonstrated that the adjusted odds of postoperative hypocalcemia were 2.2 times greater in the VDD group compared with the non-VDD group (95% CI 1.6 to 3.1,  $p < 0.01$ ), and that the adjusted odds of prolonged hospitalization following thyroidectomy were not higher in the VDD group compared with the non-VDD group ( $p = 0.13$ ).

### Sensitivity analysis

A sensitivity analysis was performed to assess the validity of using a 12-month window for 25-hydroxyvitamin D levels compared with a 90-day window. A total of 594 individuals were available for this sensitivity analysis. As shown in [tables 4 and 5](#), the sensitivity analysis replicated the findings of our larger cohort. Specifically, the average postoperative total calcium concentration was 0.4 mg/dL lower in the VDD group compared with the non-VDD group ( $p < 0.01$ ). The postoperative PTH concentration, on average, was 6.6 pg/mL higher in the VDD group compared with the non-VDD group ( $p = 0.04$ ). The postoperative magnesium and creatinine levels were also significantly higher in the non-VDD group compared with the VDD group (both  $p < 0.01$ ), and the adjusted odds of postoperative hypocalcemia were 2.5 times higher in the VDD group compared with the non-VDD group (95% CI 1.6 to 3.9,  $p < 0.01$ ).

**Table 1** Patient demographics and preoperative clinical characteristics

	VDD ( $\leq 20$ ng/mL) (n=496) Mean ( $\pm$ SD) or n (%)	Non-VDD ( $> 20$ ng/mL) (n=488) Mean ( $\pm$ SD) or n (%)	P value
Age	48 ( $\pm 15$ )	51 ( $\pm 15$ )	<0.01
Sex			0.83
Female	407 (82.1)	403 (82.6)	
Male	89 (17.9)	85 (17.4)	
BMI (kg/m <sup>2</sup> )	30.2 ( $\pm 7.8$ )	29.5 ( $\pm 7.3$ )	0.48
Preoperative vitamin D (ng/mL)	9.6 ( $\pm 8.3$ )	32.6 ( $\pm 12.0$ )	<0.01
Length of time from vitamin D measurement to surgery date (days)	14.6 ( $\pm 168.7$ )	44.3 ( $\pm 166.5$ )	<0.01
Preoperative serum calcium (mg/dL)	8.4 ( $\pm 1.0$ )	8.6 ( $\pm 0.9$ )	<0.01
Preoperative PTH (pg/mL)	36.4 ( $\pm 28.5$ )	34.8 ( $\pm 27.0$ )	0.60
Race/ethnicity			<0.01*
Caucasian	315 (63.5)	363 (74.4)	
African American	115 (23.2)	67 (13.7)	
Asian	10 (2.0)	15 (3.1)	
Native American	7 (1.4)	7 (1.4)	
Hispanic	5 (1.0)	4 (0.8)	
Other	44 (8.9)	32 (6.6)	
Urban	388 (78.2)	352 (72.1)	0.03
Rural	108 (21.8)	136 (27.9)	
Diuretic use	24 (4.8)	24 (4.9)	0.95
Proton pump inhibitor use	66 (13.3)	55 (11.3)	0.33
Surgical pathology	253 (66.2)	274 (68.0)	0.60
Malignant			
Season of surgery			0.43
Winter	114 (23.0)	94 (19.3)	
Spring	118 (23.8)	133 (27.3)	
Summer	127 (25.6)	124 (25.4)	
Autumn	137 (27.6)	137 (28.1)	
Performance of neck dissection	2 (0.4)	13 (2.7)	<0.01*

$\chi^2$  test and Fisher's exact test for categorical variables and t-test for numerical variables.

\*Fisher's exact test.

BMI, body mass index; PTH, parathyroid hormone; VDD, vitamin D deficiency.

## DISCUSSION

This retrospective, multi-institutional study demonstrates that preoperative VDD is associated with a higher risk of postoperative hypocalcemia and a slightly longer hospital stay among inpatients, but it is not associated with an increased risk of postoperative hospitalization after adjusting for baseline variables. These findings confirm our previous single-institution study.<sup>5</sup>

There is ongoing debate about the predictive value of preoperative VDD in the development of postoperative hypocalcemia. Some studies have found VDD to be predictive of postoperative hypocalcemia. For example, in a retrospective study of 166 patients with total thyroidectomy performed between 2006 and 2009, Kirkby-Bott *et al*<sup>7</sup> reported that a 19% higher proportion of vitamin D-deficient patients who underwent total thyroidectomy experienced hypocalcemia compared with those who were vitamin D-sufficient. Additionally, Kim *et al*<sup>25</sup> found the occurrence of symptomatic hypocalcemia to be 13% higher in vitamin D-deficient patients with thyroid cancer following total thyroidectomy and central compartment neck dissection.

Conversely, several studies have suggested that VDD is not a risk factor for postoperative hypocalcemia in

patients undergoing thyroidectomy. In a retrospective study of 121 patients, Griffin *et al*<sup>26</sup> found a similar incidence rate of postoperative hypocalcemia among vitamin D deficient and sufficient total thyroidectomy patients between 2009 and 2012. This study included only 11 patients in the vitamin D-sufficient group, however. In the current study, we identified 496 patients in the vitamin D-deficient group and 488 patients in the vitamin D-sufficient group. In another retrospective study of 150 patients performed between 2007 and 2013, Cherian *et al* found that VDD defined by a vitamin D concentration  $< 20$  ng/mL did not increase the risk of postoperative hypocalcemia in thyroidectomy patients.<sup>27</sup> However, this study included all thyroidectomy patients. In the current study, we excluded patients who received parathyroidectomy and/or partial thyroidectomy, thereby preventing any potential confounding effect that may arise from known and unknown effects of PTH removal or less extensive surgery on hypocalcemia. In another retrospective study of 368 patients who had total thyroidectomy performed from 2012 to 2015, VDD was defined by vitamin D concentrations  $< 50$  nmol/L (approximately 20 ng/mL), and no relationship was found between VDD and risk of postoperative hypocalcemia.<sup>28</sup> However,

**Table 2** Postoperative clinical findings and outcomes

	n	VDD ( $\leq 20$ ng/mL) (n=496)	n	Non-VDD ( $> 20$ ng/mL) (n=488)	P value
		Mean (95% CI) or n (%)		Mean (95% CI) or n (%)	
Total calcium (mg/dL)	247	8.1 (8.0 to 8.2)	421	8.4 (8.3 to 8.5)	<0.01
Within 48 hours of surgery	115	8.0 (7.8 to 8.2)	192	8.3 (8.2 to 8.4)	<0.01
After 48 hours of surgery	132	8.0 (7.8 to 8.2)	229	8.3 (8.2 to 8.4)	<0.01
Corrected calcium (mg/dL)	186	8.3 (8.2 to 8.4)	319	8.5 (8.4 to 8.6)	0.04
Within 48 hours of surgery	73	8.0 (7.8 to 8.3)	115	8.2 (8.1 to 8.3)	0.20
After 48 hours of surgery	113	8.3 (8.1 to 8.5)	204	8.5 (8.4 to 8.6)	0.06
Ionized calcium (mmol/L)	115	1.1 (1.1 to 1.1)	170	1.1 (1.1 to 1.2)	0.11
Phosphorus (mg/dL)	165	3.3 (3.1 to 3.4)	230	3.4 (3.3 to 3.5)	0.15
PTH (pg/mL)	169	35.0 (30.3 to 41.0)	308	30.6 (27.5 to 34.3)	0.10*
Magnesium (mg/dL)	144	1.7 (1.6 to 1.7)	207	1.8 (1.7 to 1.8)	<0.01
Creatinine (mg/dL)	151	0.7 (0.7 to 0.8)	297	0.8 (0.8 to 0.8)	0.01
Albumin (g/dL)	327	3.8 (3.7 to 3.9)	338	3.8 (3.7 to 3.8)	0.69
Length of stay, hours	270	35.6 (31.7 to 40.2)	232	30.3 (26.8 to 34.6)	0.03*
Same-day discharge		232 (47.5)		270 (54.4)	0.03
Intravenous calcium therapy		4 (0.8)		6 (1.2)	0.54
Calcium and/or vitamin D supplement on discharge		214 (43.2)		264 (54.1)	<0.01

$\chi^2$  test for categorical variables, ANOVA for normally distributed variables and likelihood ratio test for exponentially distributed variables.

\*Likelihood ratio test.

ANOVA, analysis of variance; PTH, parathyroid hormone; VDD, vitamin D deficiency.

these conclusions were based on unadjusted correlation analyses. In the current study, we used logistic regression modeling to report ORs appropriate for risk assessment and adjusted for imbalances present in patients' demographic variables.

Compared with our previous, single-institution study, we observed an increase in hospital stay of only 5 hours among patients with VDD, compared with an increase of 2.6 days in our previous study.<sup>5</sup> This observed difference may be attributable to patient demographics and/or regional differences in postoperative management following thyroidectomy. The increased availability of postoperative care protocols for the early detection of hypocalcemia after total thyroidectomy may have also contributed to shorter hospital stays.<sup>29-30</sup> In fact, many studies have reported an increased occurrence of outpatient thyroidectomy with an improved understanding of its safety.<sup>30-33</sup> Our current findings on hospitalization are consistent with these previous studies. In particular, Narayanan *et al*<sup>34</sup> described a low complication and reoperation rate following thyroidectomies in a retrospective study of 1447 thyroidectomy cases between 2006 and 2012. They found that 60.8% of patients were discharged within 6 hours of surgery and 27.7% were discharged within 23 hours of surgery. A small percentage of cases (1.7%) experienced symptomatic hypocalcemia and the majority of these were transient.

Somewhat surprisingly, we found that the need for calcium and/or vitamin D supplementation at discharge was significantly lower among vitamin D-deficient patients compared with vitamin D-sufficient patients. In a meta-analysis of 10 randomized controlled trials, Xing *et al*<sup>35</sup> reported that total thyroidectomy patients provided with calcium and vitamin D supplementation at discharge were at a 79% decreased risk of transient postoperative hypocalcemia compared with those discharged without such supplementation. In another meta-analysis of 3037 total thyroidectomy cases, Sanabria *et al*<sup>36</sup> reported a 25% risk reduction for postoperative hypocalcemia with routine supplementation of calcium and/or vitamin D. Similarly, Arer *et al*<sup>37</sup> described a 32% increase in the incidence of symptomatic hypocalcemia in total thyroidectomy patients given calcium supplementation compared with those without supplementation in a randomized controlled trial of 106 patients. In our study, we observed that only about half of the total thyroidectomy patients were provided with calcium and/or vitamin D supplementation at discharge.

The strengths of this study include the utilization of a large, multi-institutional database over a 9-year span which allowed for a comprehensive analysis of the effect of VDD on hypocalcemia and other postoperative clinical events following total or subtotal thyroidectomy. Our analysis was thorough in that we reported on three commonly

**Table 3** Risk of postoperative hypocalcemia and hospitalization (primary outcomes)

	Unadjusted OR (95% CI)	P value	Adjusted OR (95% CI)	P value
Total calcium ( $< 8$ mg/dL)	3.9 (3.0 to 5.0)	<0.01	2.2 (1.6 to 3.1)	<0.01
Corrected calcium ( $< 8$ mg/dL)	2.8 (2.2 to 3.7)	<0.01	1.5 (1.1 to 2.1)	0.02
Hospitalization	1.3 (1.0 to 1.7)	0.03	1.3 (0.9 to 1.8)	0.13

Adjusted for age, race, urban/rural status, neck dissection, preoperative serum calcium and preoperative serum magnesium.

**Table 4** Postoperative outcomes for sensitivity analysis of patients who had 25-hydroxyvitamin D levels obtained within 90 days of surgery (n=594)

	n	VDD ( $\leq 20$ ng/mL) (n=277) Mean (95% CI) or n (%)	n	Non-VDD ( $>20$ ng/mL) (n=317) Mean (95% CI) or n (%)	P value
Total calcium (mg/dL)	134	8.0 (7.8 to 8.2)	267	8.4 (8.3 to 8.5)	<0.01
Corrected calcium (mg/dL)	96	8.3 (8.1 to 8.4)	205	8.4 (8.3 to 8.5)	0.10
Ionized calcium (mmol/L)	72	1.1 (1.1 to 1.1)	112	1.1 (1.1 to 1.2)	0.27
Phosphorus (mg/dL)	97	3.2 (3.0 to 3.4)	144	3.4 (3.3 to 3.5)	0.15
PTH (pg/mL)	97	36.4 (30.1 to 44.9)	217	29.8 (26.2 to 34.2)	0.04*
Magnesium (mg/dL)	144	1.7 (1.6 to 1.7)	207	1.8 (1.7 to 1.8)	<0.01
Creatinine (mg/dL)	83	0.7 (0.6 to 0.7)	193	0.8 (0.8 to 0.8)	<0.01
Albumin (g/dL)	176	3.7 (3.6 to 3.8)	217	3.8 (3.7 to 3.9)	0.59
Length of stay, hours	168	34.0 (29.4 to 39.8)	169	30.7 (26.5 to 35.9)	0.21*
Same-day discharge		109 (39.4)		148 (46.7)	0.07
Intravenous calcium therapy		2 (0.7)		6 (1.9)	0.29
Calcium and/or vitamin D supplement on discharge		120 (43.3)		187 (59.0)	<0.01

$\chi^2$  test for categorical variables, ANOVA for normally distributed variables and likelihood ratio test for exponentially distributed variables.

\*Likelihood ratio test.

ANOVA, analysis of variance; PTH, parathyroid hormone; VDD, vitamin D deficiency.

used calcium analytes: total, corrected and ionized serum calcium concentrations. We further analyzed serum calcium concentration both as a continuous and a dichotomized variable. This approach allowed for numerical comparison of serum calcium concentrations between groups as well as assessment of risk associated with VDD in postoperative hypercalcemia.

Elucidating mechanisms through which VDD might result in increased post-thyroidectomy hypocalcemia and increased postoperative morbidity is beyond the scope of this study. Temporary or persistent hypoparathyroidism is widely recognized as a common complication of total thyroidectomy.<sup>1 38–40</sup> Indeed, temporary hypoparathyroidism is observed in approximately 10% of patients after total thyroidectomy, and although postoperative concentrations of PTH did not differ between the two groups in our study, our study was underpowered to demonstrate such a difference.<sup>40</sup> It is also possible that 25-hydroxyvitamin D availability at least partially determines the availability or activity of one of the hormones that are most directly responsible for calcium homeostasis, 1,25(OH)<sub>2</sub> D. In fact, it has been shown that the relationship between 25-hydroxyvitamin D concentrations and 1,25(OH)<sub>2</sub> D is not strictly linear.<sup>41 42</sup> In patients with severe VDD, it has been demonstrated that the formation of 1,25(OH)<sub>2</sub> D may be limited due to lack of substrate, and in such populations a positive correlation between serum 25-hydroxyvitamin D and 1,25(OH)<sub>2</sub> D levels is observed.<sup>43</sup>

Limitations of this study include its retrospective design and findings which show associations rather than causal

relationships. Since the possibility for selection bias exists in any observation study, a prospective study of preoperative vitamin D repletion would be beneficial in illuminating the causal effect of VDD on postoperative complications, including hypocalcemia and prolonged hospitalization. Missing postoperative laboratory variables and an inability to assess for the presence or absence of hypocalcemia symptoms were additional limitations of the study. This incompleteness likely highlights the limitations of using the de-identified Health Facts data set for clinical investigation. Furthermore, since the protocol for postoperative care likely varies between the clinics and facilities that are using Cerner's PowerChart interface, the lack of a standardized approach across the USA becomes apparent. As described by Rubin,<sup>44</sup> the missing data likely occurred at random, as opposed to not at random, in this study. As such, the cause of missingness did not induce bias to our estimates, and it is therefore statistically appropriate to proceed with the statistical analysis without accounting for complexities that arise from the missingness. Finally, although there was an imbalance between the groups with respect to the performance of neck dissection, this procedure was more commonly performed in the non-VDD group (table 1). This might be thought to favor the occurrence of hypocalcemia in the non-VDD group, but we nevertheless found more hypocalcemia in the VDD group.

In conclusion, preoperative VDD is associated with an increased risk of hypocalcemia and prolonged hospitalization following total thyroidectomy, but it is not associated with an increased risk of subsequent hospitalization. We

**Table 5** Risk of postoperative hypocalcemia and hospitalization (primary outcomes) for the sensitivity analysis of patients who had 25-hydroxyvitamin D levels obtained within 90 days of surgery (n=594)

	Unadjusted OR (95% CI)	P value	Adjusted OR (95% CI)	P value
Total calcium ( $<8$ mg/dL)	4.3 (3.0 to 6.1)	<0.01	2.5 (1.6 to 3.9)	<0.01
Corrected calcium ( $<8$ mg/dL)	3.1 (2.2 to 4.4)	<0.01	1.7 (1.1 to 2.6)	0.02
Hospitalization	1.4 (1.0 to 1.9)	0.07	1.0 (0.7 to 1.6)	0.96

Adjusted for age, race, urban/rural status, neck dissection, preoperative serum calcium and preoperative serum magnesium.

recommend that preoperative vitamin D concentrations be determined prior to the performance of total thyroidectomy and that consideration be given to preoperative vitamin D repletion in those who are deficient.

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