ORIGINAL ARTICLE

Proxy measures of vitamin D status – season and latitude – correlate with adverse outcomes after bariatric surgery in the Nationwide Inpatient Sample, 2001–2010: a retrospective cohort study

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Summary

Objective

To investigate the association between adverse surgical outcomes following bariatric surgery and proxy measures of vitamin D (VitD) status (season and latitude) in the Nationwide Inpatient Sample (NIS).

Background

Obesity is an independent risk factor for VitD deficiency ($25(OH)D < 20\,ng\,ml^{-1}$). VitD deficiency compounds the chronic inflammation of obesity, increasing the risk of adverse outcomes following bariatric surgery. Epidemiology has long used season and latitude as proxies for group VitD, as VitD status is largely determined by sun exposure, which is greatest during summer and at the Equator.

Methods

We assessed proxy measures of group VitD status. We compared surgeries in VitD Summer (July to September), Winter (January to March), and Fall/Spring (October to December and April to June) and in the North (≥37°N) vs. the South (<37°N).

Results

We identified 932,091 bariatric surgeries; 81.2% were women and 74.4% were white. Sex was unequally distributed by season ($p = 0.005$). Median age was 43.0 years (all groups). Most surgeries occurred in the North (64.8%). Adverse outcome rates ranged from 0.01% (wound infections) to 39.4% [prolonged length of stay {LOS}]. Season was inversely associated with wound infection ($p = 0.018$) and dehiscence ($p = 0.001$). Extended LOS was inversely correlated with season ($p < 0.001$). These relationships held after adjustment. Prolonged LOS ($p < 0.001$) and any complication ($p = 0.108$) were more common in the North.

Conclusions

We have demonstrated a graded relationship between seasonality and adverse outcomes following bariatric surgery. The association was strongest for dehiscence and prolonged LOS. These relationships held when using latitude. A prospective study measuring pre-operative $25(OH)D$ concentration would strengthen the case for causality in adverse surgical outcomes.

Keywords: Adverse surgical outcomes, bariatric surgery, nutrition, obesity.

Introduction

Several studies have demonstrated that most obese adults are vitamin D (VitD) insufficient ($<75\,nmol\,L^{-1}$, $30\,ng\,mL^{-1}$) or deficient ($<50\,nmol\,L^{-1}$, $20\,ng\,mL^{-1}$) (1–6). A large study by Vimaleswaran et al. found that a 10% increase in body mass index (BMI) was correlated with a 4% decrease in VitD status (5). The inverse relationship between BMI and VitD status is hypothesized to be because of sequestration of VitD by adipose tissue, reducing VitD bioavailability.

Classically, VitD maintains bone calcification, but a more varied role has been elucidated for this hormone (7). Insufficient VitD has been associated with susceptibility to infection, autoimmunity, cancer and chronic disease (8). VitD helps regulate and shows the potential to prevent inflammation that instigates chronic diseases (9,10). Obesity is associated with chronic inflammation and increased risk of chronic diseases (11,12), which may contribute to adverse outcomes, e.g. improper wound healing (13) and wound infection (14,15). Because VitD deficiency is also associated with chronic inflammation, obese individuals with insufficient VitD have extraordinary risk of adverse outcomes, particularly delayed wound healing and infection because of the role of VitD in re-epithelialization and innate immunity (16,17).

Bariatric surgery is the most successful means of long-term weight loss. There are risks of complications, which may lead to extended length of stay (LOS) post-operatively. In fact, wound infection is the most common hospital-acquired condition following bariatric surgery (18). Obese bariatric surgery patients are at an increased risk of adverse surgical outcomes. VitD deficiency is likely a risk factor that can be easily remedied pre-operatively to reduce the number and severity of adverse outcomes.

Epidemiology has long used time of year as a proxy measurement for group VitD (VitD seasonality) because the majority of VitD nutriture comes from photoproduction in the skin exposed to solar ultraviolet-B (UVB) radiation (8). In a recent study, Kasahara et al. confirmed that VitD status in the USA peaked in August and troughed in February (19). Thus, VitD Summer, the time of highest VitD status, is July to September. A recent study by Kroll et al. also showed this sinusoidal pattern of both VitD status and parathyroid hormone with over 1.5 million samples over 3 years (20). Kroll et al. also highlighted variation in latitude, showing divergence throughout the year but convergence at the time of peak status, VitD summer (20).

Another classical proxy measure of group VitD status is latitude. Individuals closer to the Equator have more opportunity to photoproduce VitD, as the poles generally receive insufficient UVB to photoproduce VitD. Skin exposed to sunlight on a cloudless day in Boston (42.2°N) from November to February did not photoproduce VitD (21). This lack of photoproduction occurred over a longer period of time farther north. Conversely, VitD photoproduction occurred all year long at 34°N (Columbia, South Carolina) (21).

The aim of our study was to investigate the association between proxy measures of group VitD status (season and latitude) and the risk of adverse outcomes following bariatric surgery. A matched pairs study comparing pre-operative gastric bypass cases to non-obese healthy controls found that bariatric candidates had significantly lower VitD status and elevated parathyroid hormone (2). The pairs were matched for age, sex, race/ethnicity, season (summer vs. winter) and latitude. This bariatric cohort also found that VitD status was higher in summer (April to September) than in winter (October to March). In lung cancer patients, VitD seasonality has been explored as it relates to surgical outcomes, showing better recurrence-free and overall survival with the highest VitD status (season plus diet) (22). Thus, bariatric surgery patients are combining the risks of obesity, vitamin D deficiency and surgery – an additive or perhaps even synergistic effect.

Methods

We conducted a retrospective cohort study using the Nationwide Inpatient Sample (NIS), a database established as part of the Healthcare Cost and Utilization Project and sponsored by the Agency for Healthcare Research and Quality. NIS contains all-payer data on inpatient stays from over 1,000 hospitals in the USA each year. NIS approximates a 20% stratified sample annually, meaning every US hospital will be sampled at least once in any 10-year period. Our analysis was performed using inpatient stays from 2001 to 2010, one 10-year period.

We restricted our analysis to bariatric surgery patients aged 18 to 65 years using International Classification of Diseases, 9th Revision, (ICD-9) codes. The codes 446.8 and 449.5 are sufficient to indicate bariatric surgery alone. The code for class 3 obesity (278.01) must be used in conjunction with the following codes to indicate bariatric surgery: 438.9, 443.1, 443.8 and 443.9. Furthermore, we excluded stays including cancer (150, 151, 152, 157 and 199), ulcer (531 and 533) or revision codes (442.1-2, 437, 445, 446.9 and 449.6-7).

This project was approved by the Johns Hopkins Medicine Institutional Review Board and was conducted in accordance with the federal Health Insurance Portability and Accountability Act of 1996 and the Declaration of Helsinki.

Primary exposure and outcomes

We used two classical epidemiological methods to indirectly asses group VitD status in bariatric surgery cases. The first technique, the primary exposure, is season, utilizing the principle that the vast majority of VitD status is determined by sun exposure (photoproduction). VitD season was defined by the following groups: VitD Summer (July to September), Winter (January to March) and Fall/Spring (October to December and April to June). These groups are based upon refined estimates of seasonality from Kasahara *et al.*, who used serum 25(OH)D (directly measured individual VitD status) (19). VitD status is highest from July to September (VitD Summer) and lowest from January to March (VitD Winter). VitD status is moderate from October to December (VitD Fall) and April to June (VitD Spring).

Latitude, the second classic technique, is based on the principle that individuals closer to the equator have more opportunity to photoproduce VitD and thus have higher VitD status as a group. For all analysis, we used the latitude of the sampled hospital. Latitude was computed based on the hospital ZIP-code from the NIS. SAS version 9.3 PROC GEOCODE (SAS Institute, Cary, NC, USA) was used to convert ZIP-codes to latitudes. To study the effect of latitude, we choose the cut-point of 37°N (Virginia Beach, Virginia). At and above 37°N, VitD photoproduction cannot occur year round, meaning that the deficiency is more likely during VitD Winter. Therefore, hospitals located at or above 37°N would be included in the north cohort, the low VitD status group, and those located below 37°N in the south cohort, the high VitD status group. We created a dichotomous variable to distinguish between locations at or above 37°N (North) and those below 37°N (South).

The primary outcomes were adverse surgical outcomes: non-healing wounds, wound infection, fascial dehiscence, suprafascial dehiscence, delayed wound healing, any complication and prolonged length of hospital stay. Outcomes were determined using ICD-9 codes, grouped as in (Table 1). Suprafascial dehiscence is defined as the early stage of dehiscence where wound separation is limited to skin and subcutaneous tissue while fascial dehiscence occurs once wound separation has deepened to include fascia and possibly muscle. Delayed wound healing is defined as the occurrence of non-healing wound, wound infection or suprafacial dehiscence. We also used the LOS variable in NIS to create the dichotomous variable extended LOS (>3 d vs.≤ 3 d).

Statistical analysis

Statistical analysis was performed using Stata 12.1 (StataCorp, College Station, TX, USA). We compared the occurrence of adverse outcomes over the spectrum of VitD seasonality. Because our outcome is dichotomous (outcome/no outcome) and our independent variables are a mix of continuous and categorical, X^2 tests and logistic regression models were used. In our logistic regression models, we utilized Charlson Comorbidity Index (CCI) to adjust for co-morbidities. CCI interprets multiple pieces of data to predict the 10-year mortality for an individual, allowing comparison between myriad of diseases in a cohort with multiple co-morbidities. We utilized ZIP-code income quartile (ZIQ) to adjust for socioeconomic status (SES). ZIQ is an approximation of the SES of the area in which an individual lives, which is predictive of the SES of an individual. To determine cost per case differences, we performed linear regression using the NIS variable TOTCHD, total charges (cleaned).

Because of the differences among groups, we utilized multiple methods of analysis. Missing data were treated as missing at random and imputed where possible. We set $\alpha = 0.05$ and $\beta = 0.20$ for all analysis and used two-sided tests. Power calculations were performed for the primary outcomes (Table 2). There is sufficient power to detect a difference between VitD Winter and Summer for all adverse outcomes except non-healing wounds. Power

Table 1 Defining adverse outcomes for bariatric surgery in the nationwide inpatient sample

Outcome variable	ICD-9 codes	Description
Non-healing wound	998.83	Non-healing surgical wound
Wound infection	998.51	Infected post-operative seroma
Fascial dehiscence	998.31	Dehiscence of surgical wound involving the fascia and/or muscle
Suprafascial dehiscence	998.3, 998.32	Dehiscence of surgical wound involving external tissues, i.e. mucosa, skin and subcutaneous tissues
Delayed wound healing	998.3, 998.32, 998.51, 998.83	All of the aforementioned description except fascial dehiscence
Any complication	998.3, 998.31, 998.32, 998.51, 998.83	All of the aforementioned description

ICD-9, International Classification of Diseases, 9th Revision.

Table 2 Power for primary outcomes in observed proportions

	Season (%)	Latitude (%)	Sex (%)	Race (%)
Non-healing wound	0.0	0.0	0.0	100.0*
Wound infection	100.0*	0.0	0.0	100.0*
Wound dehiscence	100.0*	93.0*	100.0*	100.0*
Wound separation	100.0*	99.7*	100.0*	27.7
Delayed wound healing	100.0*	99.4*	100.0*	100.0*
Any complications	100.0*	99.4*	100.0*	100.0*
Length of stay >3 d	100.0*	100.0*	11.7	100.0*

*$\beta < 0.20$.

decreased for latitude analysis with non-healing wound and wound infection being underpowered.

Results

We identified 932,091 bariatric surgeries in the NIS dataset from 2001 to 2010 (Table 3). Most surgeries (51%) occurred during the moderate VitD season (Spring/Fall) while 26% occurred during high VitD season (Summer) and 23% during low VitD season (Winter). The sampled hospitals were mostly urban (83.3%), which was unchanged throughout the seasons. The median ZIQ was 2.68 with no variation between the seasons. More surgical procedures were performed in the North (64.8%) and particularly during VitD Winter ($p < 0.001$). The majority of procedures were performed in women (81.2%) and in White people (74.4%). Sex was unequally distributed among the seasons, $p = 0.005$. Median age was 43.0 years in all season.

(Table 3) also shows the demographics displayed by latitude (north vs. south). We found the north cohort to be slightly wealthier ($p < 0.001$). The large proportion of women (81%) and median age (43.0 years) is consistent between geographic regions. The north cohort is more prominently White (77.1% vs. 70.4%, $p < 0.001$), largely because of fewer Black people and Hispanics.

Table 3 Nationwide inpatient sample bariatric surgery demographics

Cohort demographics by season

	Total	Winter	Spring/Fall	Summer	*p*-value
Surgeries	932,091	215,060 (23%)	475,186 (51%)	241,845 (26%)	<0.001*
Urban	83.3%	83.7%	83.3%	82.8%	0.152
ZIP-code income (quartile)	2.68 ± 0.06	2.68 ± 0.07	2.68 ± 0.06	2.68 ± 0.06	0.628
North (≥37°N)	64.8%	66.3%	64.3%	64.4%	0.007*
Female	81.2%	80.8%	81.0%	81.6%	0.005*
Age (years)	43.0 ± 0.18	43.0 ± 0.21	43.0 ± 0.19	43.0 ± 0.21	<0.001*
Race/ethnicity					0.634
White	74.4%	74.8%	74.2%	74.6%	
Black	12.6%	12.6%	12.7%	12.4%	
Hispanic	8.4%	8.0%	8.5%	8.7%	
Asian/PI	0.5%	0.6%	0.5%	0.5%	
Native American	0.6%	0.6%	0.7%	0.5%	
Other	3.4%	3.4%	3.4%	3.3%	

Cohort demographics by latitude

	Total	North (≥37°N)	South (<37°N)	*p*-value
Surgeries	932,091	603,940 (65%)	328,151 (35%)	<0.001*
Urban	83.3%	81.7%	85.7%	0.062
ZIP-code income (quartile)	2.68 ± 0.06	2.75 ± 0.08	2.55 ± 0.08	<0.001*
Female	81.2%	81.3%	80.9%	0.444
Age (years)	43.0 ± 0.18	43.0 ± 0.23	42.9 ± 0.29	0.677
Race/ethnicity				<0.001*
White	74.4%	77.1%	70.4%	
Black	12.6%	12.0%	13.6%	
Hispanic	8.4%	6.6%	11.3%	
Asian/PI	0.5%	0.5%	0.6%	
Native American	0.6%	0.4%	0.9%	
Other	3.4%	3.5%	3.3%	

*Significant at $p < 0.05$ level.
PI, Pacific Islander.

Frequency of adverse surgical outcomes

(Table 4) shows the frequency of adverse outcomes by season, ranging from $n = 72$ for wound infection and non-healing wounds to $n = 367,245$ for prolonged LOS. Fascial dehiscence, suprafascial dehiscence, delayed healing and any complication are significantly different by season (Figure 1). All outcomes except non-healing wound decrease in frequency with increasing VitD season.

(Table 4) also shows the frequency of adverse outcomes by latitude (north vs. south). Prolonged LOS was more common in the north ($p < 0.001$). The increased occurrence of complications in the north vs. the south did not reach statistical significance (Figure 2).

Logistic regression analysis: continuous

(Table 5) shows logistic regression for adverse outcomes and VitD seasonality as a spectrum both unadjusted (Model 1) and adjusted for potential confounders (Models 2 and 3). VitD seasonality is significantly correlated with suprafascial dehiscence, delayed wound healing, any complication and prolonged LOS in all models. For each season closer to VitD Winter, the

odds of experiencing suprafascial dehiscence (OR 1.45–1.49), delayed wound healing (OR 1.53–1.56), any complication (OR 1.45–1.46) and LOS (OR 1.04–1.05) significantly increases. Fascial dehiscence is significantly correlated with VitD seasonality in Models 1 and 2 (OR 1.30–1.33). The strong trend observed between VitD seasonality and wound infection is significant in Model 1 (OR 2.50).

Logistic regression analysis: dichotomous

We also analysed the association of adverse outcomes comparing the highest VitD season (Summer) to the lowest (Winter) (Table 4). Suprafascial dehiscence (OR 1.89–2.07), delayed wound healing (OR 2.13–2.29), any complication (OR 1.51–2.10) and prolonged LOS (OR 1.09–1.10) remained significant in all models. Fascial dehiscence (OR 1.82–1.92) was significant in Models 1 and 2. Despite strong trends, neither non-healing wound (OR 1.88–2.46) nor wound infection (OR 4.38–7.56) reached statistical significance. Wound infection was borderline significant in Model 1 (OR 7.56, $p = 0.059$).

We performed logistic analysis to determine the association of latitude with adverse outcomes (data not

Table 4 Frequency of adverse outcomes following bariatric surgery

Frequency of wound complications by season following bariatric surgery

	Total		Winter		Spring/Fall		Summer		
	n	%	*n*	%	*n*	%	*n*	%	*p*-value
Non-healing wound	72	0.01	24	0.01	34	0.01	14	0.01	0.627
Wound infection	76	0.01	36	0.02	35	0.01	<11	0.00	0.060
Fascial dehiscence	666	0.07	174	0.08	385	0.08	107	0.04	0.030*
Suprafascial dehiscence	804	0.09	289	0.13	358	0.08	157	0.07	0.001*
Delayed wound healing	948	0.10	349	0.16	427	0.09	172	0.07	<0.001*
Any complication	1608	0.17	523	0.24	811	0.17	274	0.11	<0.001*
Length of stay >3 d	367,245	39.40	88,757	41.27	184,187	38.76	94,301	38.99	<0.001*

Frequency of wound complications by latitude following bariatric surgery

	Total		North		South		
	n	%	*n*	%	*n*	%	*p*-value
Non-healing wound	72	0.01	46	0.01	26	0.01	0.895
Wound infection	76	0.01	56	0.01	20	0.01	0.477
Fascial dehiscence	666	0.07	456	0.08	210	0.06	0.416
Suprafascial dehiscence	804	0.08	577	0.10	227	0.07	0.091
Delayed wound healing	948	0.10	674	0.11	274	0.08	0.105
Any complication	1608	0.17	1124	0.19	484	0.15	0.107
Length of stay >3 d	367,244	39.40	261,067	43.23	106,177	32.36	<0.001*

*Significant at $p < 0.05$ level.
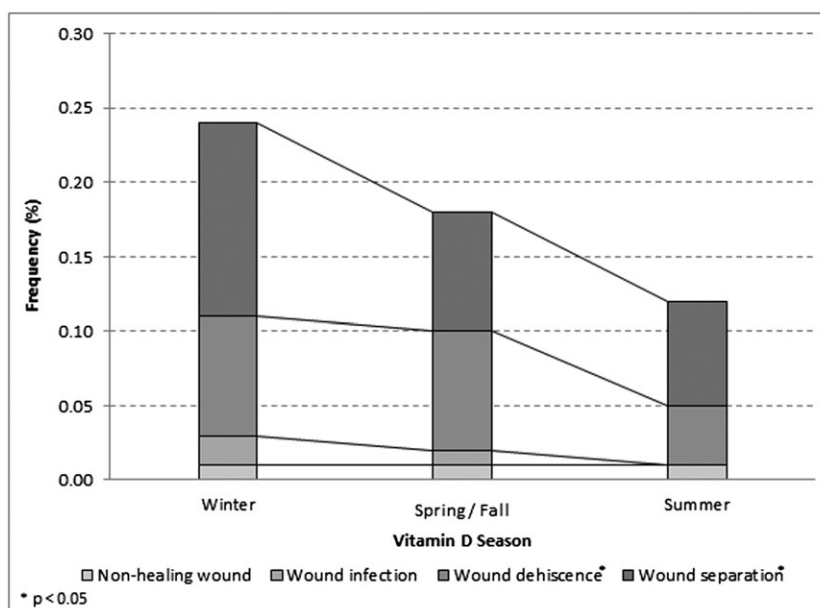
Figure 1 Seasonality of wound complications following bariatric surgery in the nationwide inpatient sample, 2001–2010. Vitamin D Winter (January to March) is the time of lowest vitamin D status while Summer (July to September) is the highest. Spring/Fall (October to December and April to June) is the intermediate season.
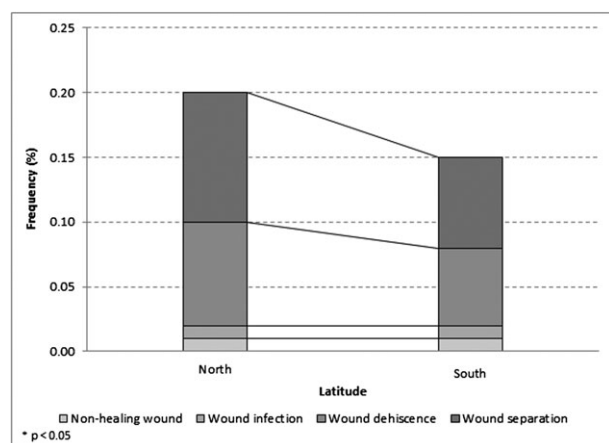
Figure 2 Latitude and wound complications following bariatric surgery. The frequency of wound complications following bariatric surgery in the north cohort (≥37°N) vs. the south cohort (<37°N) in the Nationwide Inpatient Sample, 2001–2010.

shown). Trends similar to seasonality were observed. The only significant relationship with latitude was prolonged LOS (OR 1.42–159), which held after adjustment for season, age, sex, race, CCI and ZIQ.

Adverse surgical outcomes by Sex and race

Finally, we analysed differences between sex and race (Table 6). Fascial dehiscence and any complication were significant in all stratums, meaning there is a significantly higher risk of complications in men compared with women and White people compared with non-White people. Suprafascial dehiscence, fascial dehiscence, delayed wound healing and any complication were significantly more likely in males. Fascial dehiscence and any complication were significantly more likely in White people.

Discussion

We have demonstrated a graded relationship between seasonality (proxy for group VitD status) and adverse outcomes following bariatric surgery. Our results support the potential role of VitD in preventing complications following bariatric surgery, especially as it pertains to wound healing and infection as well as prolonged LOS in the hospital. The association was strongest for suprafascial dehiscence ($p = 0.001$) and fascial dehiscence ($p = 0.034$), and this relationship held after adjusting for latitude, age, sex, race, CCI and SES. Extended LOS postoperatively was also correlated with VitD season, $p < 0.001$ in all models. The cost per case was $680.63 higher in VitD Winter than Summer and $8,961.84 in the north vs. the south, some of the difference in cost likely results from longer hospital stays.

Non-healing wounds occurred in just 0.01% of bariatric surgeries overall and in each season. As with other infrequent outcomes, a relationship may be significant in future studies directly measuring individual VitD status – serum 25(OH)D concentration – instead of a proxy

Table 5 Odds of adverse outcomes following bariatric surgery

VitD seasonality as a spectrum

	Model 1		Model 2		Model 3	
	Odds ratio	*p*-value	Odds ratio	*p*-value	Odds ratio	*p*-value
Non-healing wound	1.40	0.389	1.61	0.294	1.67	0.303
Wound infection	2.50	0.018*	1.97	0.137	1.98	0.133
Fascial dehiscence	1.30	0.025*	1.33	0.037*	1.32	0.053
Suprafascial dehiscence	1.49	0.001*	1.45	0.022*	1.46	0.023*
Delayed wound healing	1.56	<0.001*	1.53	0.006*	1.55	0.006*
Any complication	1.46	<0.001*	1.45	<0.001*	1.46	<0.001*
Length of stay >3 d	1.05	<0.001*	1.04	0.001*	1.05	<0.001*

Model 1: Unadjusted
Model 2: Adjusted for latitude, age, sex and race (White people vs. non-White people)
Model 3: Adjusted for latitude, age, sex, race, Charlson Comorbidities Index and ZIP-code income quartile

VitD Winter vs. Summer

	Model 1		Model 2		Model 3	
	Odds ratio	*p*-value	Odds ratio	*p*-value	Odds ratio	*p*-value
Non-healing wound	1.88	0.390	2.46	0.303	2.44	0.305
Wound infection	7.56	0.059	4.38	0.187	4.44	0.184
Fascial dehiscence	1.82	0.034*	1.92	0.048*	1.85	0.063
Suprafascial dehiscence	2.07	0.001*	1.89	0.019*	1.89	0.019*
Delayed wound healing	2.29	<0.001*	2.13	0.005*	2.13	0.005*
Any complication	1.51	0.007*	2.10	<0.001*	2.07	<0.001*
Length of stay >3 d	1.10	<0.001*	1.09	<0.001*	1.10	<0.001*

Model 1: Unadjusted
Model 2: Adjusted for latitude, age, sex and race (White people vs. non-White people)
Model 3: Adjusted for latitude, age, sex, race, Charlson Comorbidities Index and ZIP-code income quartile

*Significant at $p < 0.05$ level.

measurement. Furthermore, adverse outcomes appeared to be more common in the north where solar UVB radiation is less available for VitD photoproduction with prolonged LOS reaching statistical significance ($p < 0.001$). Kroll *et al.* showed that the differences in VitD status by latitude within the USA may be small, particularly during VitD Summer and Spring/Fall (20).

Our analysis also revealed that suprafascial dehiscence, fascial dehiscence, delayed wound healing and any complication were significantly more likely in men compared with women. This has been reported in other studies. It is possible that wound complications occur more frequently in males because of decreased production of collagen, leading to a reduced capacity for wound healing (23,24).

Fascial dehiscence and any complication were significantly more likely in White people compared with non-White people. This seems counter to the knowledge that White people are better able to photoproduce VitD given the same dose of UVB radiation. However, white skin also tends to have less efficient barrier function. Individuals of European descent are more likely to have mutations in proteins required for the barrier function of skin. One such mutation occurs in the gene for filaggrin. This mutation has tracked with low melanin production and increased ability to photoproduce VitD (25), which may explain why White people are more likely to experience wound complications in this cohort. Furthermore, VitD has been shown to impact claudins and cadherins, proteins required for skin integrity (26,27).

With the obesity epidemic on the rise, surgery in obese patients will become more common. It is crucial to optimize the results of these surgeries by reducing alterable risk factors. The potentially synergistic role of VitD insufficiency and obesity on chronic inflammation may lead to increased risk of poor wound healing and infection. If we can supplement patients with VitD prior to surgery, it is possible we will decrease the rates of wound infection and delayed wound healing and limit the LOS required post-operatively. A study examining the effect of VitD status directly – serum 25(OH)D concentration – instead of a proxy is the logical next step. Ultimately, a randomized,

Table 6 Complications following bariatric surgery stratified by sex and race

	Males		Females		
	n	%	n	%	p-value
Total	175,259		754,346		
Non-healing wound	47	0.01	64	0.01	0.496
Wound infection	11	0.01	66	0.01	0.647
Wound dehiscence	253	0.14	414	0.05	<0.001*
Wound separation	232	0.13	573	0.08	0.001*
Delayed wound healing	251	0.14	697	0.09	0.007*
Any complication	507	0.29	1,100	0.15	<0.001*
Length of stay >3 d	68,984	39.4	297,743	39.5	0.846

	White		All others		
	n	%	n	%	p-value
Total	547,712		188,175		
Non-healing wound	44	0.01	<11	0.00	0.515
Wound infection	47	0.01	<11	0.00	0.274
Wound dehiscence	437	0.08	72	0.04	0.006*
Wound separation	393	0.07	122	0.06	0.663
Delayed wound healing	478	0.09	136	0.01	0.413
Any complication	919	0.17	203	0.11	0.017*
Length of stay>3 d	205,135	37.5	66,244	35.2	0.061

*Significant at $p < 0.05$ level.

controlled trial will need to be performed to establish a causal role for VitD insufficiency in adverse outcomes.

The Nationwide Inpatient Sample contains data at the discharge level, not the individual level. Therefore, it is possible that some of the individuals were readmitted for complications at a later date, and we are unable to account for this. This database also lacks some variables that could affect adverse outcomes or VitD status, such as BMI or length and difficulty of the surgical procedure. Future prospective studies should include these measures if possible.

As in other bariatric surgery populations, we found smaller numbers of men and non-White people. Because of these low numbers, the results in these stratums were less significant than in women and White people, but the directionality of the relationships remained the same. This is an inherent issue to studying bariatric surgery at this time.

Furthermore, VitD season is a proxy, not the direct measure of VitD status, which is serum 25(OH)D concentration. For any individual, serum 25(OH)D could be significantly higher or lower than we would expect for the VitD season, e.g. if a patient took VitD supplements. It is also possible that there are seasonal differences in other factors that could contribute to the observed differences, such as winter being a time of increased exposure to infectious agents or that stays were extended because of snow storms. Adjusting for latitude should help account for effects such as snow storms. Future studies should be conducted measuring 25(OH)D to confirm our findings.

The large sample size afforded by the NIS has allowed for detection of differences in adverse outcomes using proxy measures of VitD status where obtaining serum 25(OH)D concentration is not currently available. The number of surgeries has also yielded less common adverse outcomes like wound infection in sufficient number to detect a difference between VitD seasons.

By adding latitude into NIS, we strengthened our analysis. Latitude is an additional proxy measure of group VitD status, allowing us to confirm the results of our analysis utilizing seasonality. Furthermore, latitude is a potential effect modifier of the relationship between seasonality and adverse outcomes. Controlling for latitude enhanced our analysis of the primary outcome measure, season.

Adverse outcomes following bariatric surgery are most common from January to March when VitD status is lowest (VitD Winter). The strongest correlations were observed for suprafascial dehiscence, fascial dehiscence and extended LOS. Adverse outcomes appeared to be more common in the northern latitudes where solar UVB radiation is less available for VitD photoproduction with prolonged LOS reaching statistical significance ($p < 0.001$). VitD supplementation, an easy and inexpensive treatment, may mitigate these risks and prevent adverse outcomes following bariatric surgery. A prospective study measuring pre-operative 25(OH)D concentration would strengthen the case for causality in adverse surgical outcomes.

Conflict of Interest Statement

No conflict of interest was declared.

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