





# Nutritional Assessment of Denture Wearers Using Matched Electronic Dental-Health Record Data

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## Keywords

Removable dentures; diet; nutrition; malnutrition; older adults; dental informatics; electronic health record; electronic dental record; data analytics.

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## Abstract

**Purpose:** To assess the nutritional profile of denture wearers through a retrospective cohort study using nutritional biomarkers from matched electronic dental and health record (EDR-EHR) data.

**Materials and methods:** The case group (denture wearers) included matched EDR-EHR data of patients who received removable partial, complete, and implant-supported prosthodontic treatments between January 1, 2010 and December 31, 2018, study time. The control (nondenture wearers) group did not have recorded denture treatments and included patient records within 1 year of the denture index date (first date of case patients' receiving complete or partial denture) of the matching cases. The qualified patients' EDR were matched with their EHR based on the availability of laboratory reports within 2 years of receiving the dentures (index date). Nutritional biomarkers were selected from laboratory reports for complete blood count, comprehensive and basic metabolic profile, lipid, and thyroid panels. Summary statistics were performed, and general linear mixed effect models were used to evaluate the rate of change over time (slope) of nutritional biomarkers before and after the index date. Likelihood ratio tests were performed to determine the differences between dentures and controls.

**Results:** The final cohort included 10,481 matched EDR-EHR data with 3,519 denture wearers and 6,962 controls that contained laboratory results within the study time. The denture wearers' mean age was  $57 \pm 10$  years and the control group was  $56 \pm 10$  years with 55% females in both groups. Pre-post analysis among denture wearers revealed decreased serum albumin ( $p = 0.002$ ), calcium ( $p = 0.039$ ), creatinine ( $p < 0.001$ ) during the post-index time. Hemoglobin (Hb) was higher pre-index, and was decreasing during the time period but did not change post-index ( $p < 0.001$ ). Among denture wearers, completely edentulous patients had a significant decrease in serum albumin, creatinine, blood urea nitrogen (BUN), but increased estimated glomerular filtration rate (eGFR). In partially edentulous patients, total cholesterol decreased ( $p = 0.018$ ) and TSH ( $p = 0.004$ ), BUN ( $p < 0.001$ ) increased post-index. Patients edentulous in either upper or lower arch had decreased BUN and eGFR during post-index. Compared to controls, denture wearers showed decreased serum albumin and protein ( $p = 0.008$ ), serum calcium ( $p = 0.001$ ), and controls showed increased Hb ( $p = 0.035$ ) during post-index.

**Conclusions:** The study results indicate nutritional biomarker variations among denture wearers suggesting a risk for undernutrition and the potential of using selected nutritional biomarkers to monitor nutritional profile.

The interrelationship between aging and tooth loss in the 21st century has changed from the 1970s with a decrease in partially or completely edentulous individuals.<sup>1,2</sup> Nevertheless, disparities in access to oral care lead to tooth loss, especially in populations adversely impacted by race and other socio-economic factors.<sup>2-5</sup> Risk factors such as smoking, periodontitis, untreated caries, disability, and injuries also lead to complete or partial tooth loss.<sup>6,7</sup> In addition, the population older than 65 years is expected to double in the United States to 83.7 million by 2050; and an increased rate of 24% by 2060.<sup>8-11</sup> This trend suggests that the percentage of the older population with edentulousness will increase.<sup>11-14</sup> Essentially, the decline in edentulism is offset by the overall increase in the aging population. Consequently, edentulism remains a relevant problem for the foreseeable future.

Edentulism affects both oral and systemic health.<sup>15-17</sup> Lack of proper food intake affects the nutritional status of individuals with tooth loss and thereby affects their overall health.<sup>18,19</sup> Individuals who are edentulous, partially dentate, or wearing any prosthesis, are shown to be at risk for malnutrition.<sup>20-26</sup> Experimental and observational evidence demonstrates an association between tooth loss, diet, and nutrition.<sup>27</sup> Studies have reported the risk of malnutrition with edentulousness among older adults with or without prosthetic rehabilitation. Adult patients who were completely or partially edentulous and wore a dental prosthesis lacked specific nutrients and were at risk for malnutrition.<sup>28-32</sup> Masticatory or chewing inefficiency was more common among removable complete denture wearers than partial denture wearers.<sup>32-36</sup> Lower nutritional profiles were observed among older adults with either a mandibular or a maxillary complete denture placed opposing natural dentition.<sup>14,24,37,38</sup> However, these studies used cross-sectional study designs, included a small sample size, and short duration, or with no longitudinal follow-up.<sup>29,31,39</sup> In addition, studies that administered self-reported questionnaires on dietary intake have inherent limitations such as recall bias, inability to assess health behavior over time, selective inclusion, and lack of objective measurement.<sup>25,26,29,31</sup>

Randomized clinical trials reported a decrease in nutritional biomarkers such as serum folate, vitamin B<sub>12</sub>, and serum albumin among removable prosthodontic patients but were not statistically significant.<sup>40-44</sup> Furthermore, clinical studies have also demonstrated the need for dietary counseling during prosthodontic treatment.<sup>18,45-47</sup> Despite these studies, nutritional counseling of patients who receive prosthodontic treatments is not part of dental and medical care. One of the potential reasons is these studies included few study participants and short follow-up, thus limiting the generalizability of the results. A recent systematic review showed that dentures helped reduce the risk of undernutrition in the edentulous, however, the eating function and eating related quality of life was reduced compared to dentate individuals. Compared to dentate individual's denture wearers had a lower dietary intake, but studies were of poor quality with no application of validated nutritional assessment.<sup>48</sup>

While clinical research generates high-quality evidence on a defined population, it may exclude patients with multiple comorbidities and older patients. Besides, it is costly, takes years to generate results, and may not be generalizable to the treat-

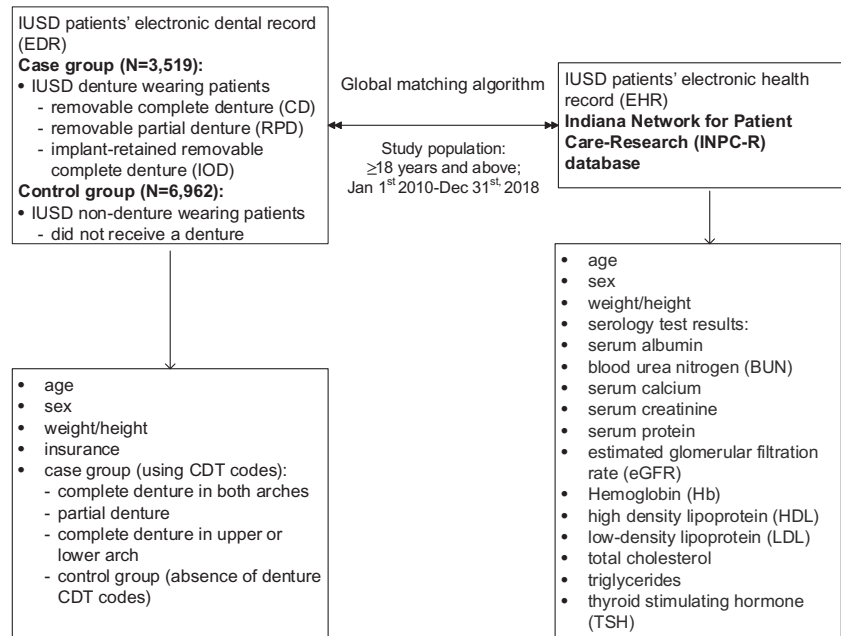
ment effectiveness delivered in real-world settings.<sup>49,50</sup> With the digitization of patient care documentation, harnessing electronic health record (EHR) and electronic dental record (EDR) data allows the study of all patients and facilitates longitudinal studies, which are not possible with traditional methods. The potential to link data from disparate data sources such as the EDR and EHR of patients also enables us to study the effect of oral health treatments on their overall health over a longer time.

Therefore, the objective of this study was to assess longitudinally the nutritional status among denture wearers; and to compare the profile of denture and nondenture wearing patients using nutritional biomarkers from laboratory reports. Laboratory data, specifically markers for malnutrition from complete blood count (CBC), comprehensive metabolic profile (CMP), basic metabolic profile (BMP), lipid and thyroid panel tests, anthropometrics (weight, height, and body mass index (BMI), demographics, and the presence of dental insurance, were retrieved from the EHR and EDR data. To the best of our knowledge, studies utilizing laboratory values of nutritional biomarkers in the serum and urine samples present in the EHR and linking with EDR data have not been reported previously.

## Materials and methods

Institutional Review Board (IRB) approval, with exempt status, was obtained from the Indiana University IRB (#: 910445123). This retrospective longitudinal study included partially and completely edentulous adult (18 years and above) patients who received removable prosthodontic treatment and implant overdentures between January 1, 2010 and December 31, 2018, at the Indiana University School of Dentistry (IUSD) clinics. The procedures included complete dentures, removable partial dentures, and implant-retained overdentures or over-partial dentures. The procedures were identified using the American Dental Association's (ADA) Code on Dental Procedures and Nomenclature (CDT) for prosthodontic treatments from the EDR (axiUm<sup>®</sup>-EXAN) (see Table S1) used at IUSD. Next, patients who received these treatments were identified using their EDR data, then matched with their EHR data available in the Indiana Network for Patient Care Research Database (INPC-R). INPC is derived from the statewide Indiana health information exchange (IHIE) with data from over 100 separate health-care entities in Indiana, including hospitals, health networks, and insurance providers.<sup>52</sup> A consolidated patient file is created for each patient from multiple sources. Mainly, there are five participating medical systems from over 14,000 practices and 40,000 providers.<sup>52</sup> Data from clinical encounters, laboratory and diagnostic reports, radiology, medication, insurance, and other sources comprise greater than approximately 10 billion pieces of information.<sup>51</sup> Figure 1 describes the process of identifying the EDR of eligible patients and linking them with their EHR data.

Patients with a minimum of one visit documented in the EHR within 2 years after receiving the dentures were included in the study. In addition to the criteria described above, patients with fixed prosthesis in addition to a removable denture in an opposing/contralateral arch were included. Patients who only had fixed prosthesis were excluded. Patients with systemic



**Figure 1** Flow diagram describes the process of identifying the electronic dental record (EDR) of eligible patients and linking them with their electronic health record (EHR) data using demographic, clinical, and laboratory variables.

diseases, infections, cognitive decline, or orofacial motor disorders were not excluded. Patients with no follow-up visits or no available information in the EDR or EHR were excluded. Patients with no laboratory records during the study time period were also not included.

Two controls (nondenture wearers) per case (denture wearer), matched by age and gender and who had matched EDR-EHR data, were included to detect any significant differences between denture wearers and controls in their nutritional status. Eligible patients from the matched EDR-EHR data were identified and queried for study-specific data. From the EDR, the following demographic information was retrieved: age, sex, presence of insurance, treatment history (including dates of treatment), and completed treatments identified by CDT procedure codes. Denture index date was defined as the first date for a patient's complete or partial denture treatment within the January 1, 2010 and December 31, 2018, study time. For the case group (denture wearers), the pre- and post-index dates were defined as  $\pm 2$  years of the denture index date. The index date for nondenture wearing patients (hereafter referred to as controls) was matched within  $\pm 1$  year of the denture index date of the matching cases. The pre-index date refers to the time before denture insertion, and post-index date refers to the time after denture insertion. Terms pre- and post-index dates are used throughout the article for the case and control groups. Dentition status was further classified into three groups by treatments received: (1) completely edentulous, based on conventional complete denture (CD) and implant-supported overdenture (IOD); (2) edentulous either in the upper or lower arch (CD or IOD); and (3) partially edentulous (removable partial denture [RPD]); overdenture-supported partial dentures (OPD).

Data retrieved from the EHR contained demographic information, patient's medical conditions recorded with ICD9/10 diagnostic codes, height and weight information, and selected laboratory reports. Laboratory information from the EHR within  $\pm 2$  years of the denture index date was also retrieved. The laboratory records included those performed as part of the annual physical examination: complete blood count (CBC) with differential and platelets test, comprehensive metabolic panel (CMP), basic metabolic panel (BMP), lipid panel, and thyroid function tests. The following laboratory values were retrieved from the laboratory records which may qualify as a nutritional marker: serum albumin, calcium, creatinine, protein, hemoglobin (Hb), blood urea nitrogen (BUN), estimated glomerular filtration rate (eGFR), total cholesterol, low-density lipoprotein (LDL), high-density lipoprotein (HDL), triglycerides (TGL), and thyroid-stimulating hormone (TSH) values.<sup>53–56</sup>

### Statistical analysis

Data analysis was performed using the statistical analysis software, SAS® version 9.4 (SAS Institute, Inc., Cary, NC). Summary statistics of patient characteristics and nutritional outcome measures were included for both denture wearers and matched controls. Subgroup analyses were based on the three levels (completely edentulous, edentulous either in the upper or lower arch, partially edentulous) of the dentition status of the denture wearers. The analyses focused on the rate of change or slope for nutritional biomarkers between pre- and post-index for denture wearers and controls. A slope-based model was used to detect any changes that may be happening pre-index when comparing to post-index. General linear mixed-effects

models (GLMM) were used to compare laboratory measurements from the EHR with pre-post index dates from the EDR. Random effects slope-based models evaluated the mean rates of change over time and tested the differences between pre- and post-index dates. Random effects allowed individual variances pre- and post-index to be included in the model and individual patient-specific intercepts and slopes. Finally, the comparative analysis included likelihood ratio tests in determining whether the slopes were different for denture wearers and controls. A 5% significance level was used for all tests.

## Results

### Demographic characteristics of denture (case) and control patients

From the EDR, 6,834 distinct patients with records of receiving removable complete/partial dentures or implant/abutment retained dentures qualified for the study. Approximately 52% ( $n = 3,519$ ) of the patients' EDR matched their EHR that contained laboratory results within the study time. The total number and type of prosthodontic procedures and CDT codes used for 3,519 denture wearers are listed in Table S2. Forty-one percent ( $N = 1,430$ ) of the cases had maxillary (D5110) and mandibular (D5120) complete dentures followed by maxillary and mandibular partials with cast metal frame along with either one of the upper or lower complete dentures. Distribution of denture wearers based on dentition status revealed that 46% of the patients were completely edentulous, followed by partially edentulous patients (31%); 23% of patients were either edentulous in the upper or lower arch opposing a natural dentition or any partial denture.

The average age of the case-cohort was 57 years  $\pm 10$  (mean  $\pm$  SD), ranging from 18 to 84 years. Females constituted 55% in both the case and control groups (see Table 1). Sixty-three percent of denture wearers were White, followed by 30% Black, and 5% Hispanic. Patients belonging to other races/ethnicities were less than 1%. Sixty-one percent of the case-cohort lacked dental insurance. Sixty-four percent of completely edentulous patients did not have insurance, followed by 63% of completely edentulous patients in the upper or lower arch and 56% of partially dentate patients (Table S3). In addition, the distribution of age, sex, ethnicity, and insurance information of denture wearers classified based on their dentition status is provided in the supplementary information (see Table S3).

Based on the 2:1 ratio of controls to denture wearers, the control group included 6,962 patients without dentures with an average age of 56  $\pm 11$  (mean  $\pm$  SD) years. Forty-two percent of the controls were White followed by Black (13%) and Hispanic (3%), and a large percentage (40%) were unknown race/ethnicity. Like denture wearers, 61% of control patients did not have insurance and 39% had insurance. Demographic attributes for the study cohort, including denture and control patients, are listed in Table 1.

The number of subjects, total, average, and range of the number of measurements per subject for nutritional biomarkers obtained from the laboratory values within the index date for both denture wearers and controls are provided in Table S4. The EHR had the same laboratory results recorded from mul-

**Table 1** Demographic characteristics of denture wearers ( $N = 3,519$ ) and control group patients ( $N = 6,962$ )

Variables	Denture wearers		Controls	
	Frequency (N)	%	Frequency (N)	%
Age in years				
18-20	2	(<1)	13	(<1)
21-30	55	(2)	121	(2)
31-40	199	(6)	501	(7)
41-50	585	(17)	1,359	(20)
51-60	1,212	(34)	2,445	(35)
61-70	1,231	(35)	2101	(30)
71-80	233	(7)	420	(6)
$\geq 81$	2	(<1)	2	(<1)
Sex				
Female	1,926	55	3,812	55
Male	1,591	45	3,147	45
Unknown	2	< 1	3	<1
Race/Ethnicity				
Caucasian/White	2,220	63	2,896	42
African American/Black	1,039	30	904	13
American Indian/Alaskan	3	<1	4	<1
Asian	43	1	103	1
Bi-Racial/Multiracial	13	<1	4	<1
Hispanic/Latino	166	5	217	3
Other/Blank	31	1	34	<1
Unknown	4	<1	2,800	40
Insurance				
Yes	1,362	39	2,701	39
No	2,157	61	4,261	61

iple sources. Therefore, multiple laboratory records would be available for the same patient. Duplicates were removed, and one record was included per patient per day. Table 2 lists the means and slopes (rates of change over time) for the pre- and post-index periods for denture wearers and controls. The normal ranges of the nutritional biomarkers are also shown in Table 2.

### Pre-post analyses of nutritional biomarkers for denture wearers and controls

The rate of change over time (slope) for each outcome variable measuring nutritional status during pre- and post-index dates was evaluated using GLMM. The pre-post analyses showed decreasing serum albumin ( $p = 0.002$ ) and calcium ( $p = 0.039$ ) during the post-index period for denture wearers (Table 2). Table 3 illustrates the changes in nutritional biomarkers (slope) classified by patients' dentition status. The results revealed no changes in serum albumin during the pre-index period but a decrease during the post-index ( $p = 0.001$ ) period for completely edentulous patients. Serum albumin decrease was not significant for the other two dentition groups. Serum calcium for edentulous patients in the upper or lower arch increased pre-index but decreased post-index ( $p = 0.016$ ). Although there was a decrease in the slope for serum calcium during the post-index time, they were not statistically significant for completely edentulous ( $p = 0.415$ ) and partially edentulous

**Table 2** Pre-post analysis for denture wearers and controls

Measurement	Time	Denture (case group) patients			Nondenture (control group) patients			Normal values
		Mean (SE)	Slope (SE)	p-Value	Mean (SE)	Slope (SE)	p-Value	
Weight (kg)	Pre	80.76 (0.37)	-0.0005 (0.0004)	0.414	81.76 (0.28)	0.0002 (0.0002)	0.003*	125-168 lbs.56.69-76.20 kg
	Post	80.39 (0.36)	-0.0010 (0.0003)		81.74 (0.28)	-0.0007 (0.0002)		
BMI	Pre	27.96 (0.12)	-0.0001 (0.0001)	0.135	28.11 (0.09)	0.0001 (0.0001)	0.004*	18.5-24.9
	Post	27.84 (0.11)	-0.0004 (0.0001)		28.12 (0.09)	-0.0002 (0.0001)		
HDL	Pre	47.45 (0.39)	0.0033 (0.0015)	0.398	49.56 (0.26)	0.0007 (0.0004)	0.612	Men: 45-70 mg/dL Women: 50-90 mg/dL
	Post	48.69 (0.34)	0.0016 (0.0007)		50.18 (0.25)	0.0011 (0.0004)		
LDL	Pre	103.31 (0.87)	0.0107 (0.0040)	0.204	107.39 (0.55)	-0.0040 (0.0013)	0.685	Optimal: <100 mg/dL Above optimal: 100-129 mg/dL Borderline high: 130-159 mg/dL High: 160-189 mg/dL Very high: 190 mg/dL
	Post	99.88 (0.73)	-0.0042 (0.0017)		104.46 (0.54)	-0.0050 (0.0013)		
Total cholesterol	Pre	177.92 (1.15)	-0.0029 (0.0055)	0.942	183.63 (0.75)	-0.0037 (0.0018)	0.651	<150 mg/dL
	Post	175.84 (0.94)	-0.0022 (0.0025)		180.70 (0.70)	-0.0050 (0.0016)		
Triglyceride	Pre	155.87 (3.00)	-0.0017 (0.0150)	0.961	147.43 (1.82)	-0.0037 (0.0047)	0.242	Normal <150 mg/dL Borderline high: 150-199 mg/dL High: 200-499 mg/dL Very high: ≥500 mg/dL
	Post	152.57 (2.51)	-0.0024 (0.0069)		142.73 (1.70)	-0.0131 (0.0044)		
Serum albumin	Pre	4.06 (0.01)	0.0001 (0.0001)	0.002*	4.08 (0.01)	-0.0001 (0.0000)	0.390	3.4-5.4 g/dL
	Post	4.00 (0.01)	-0.0001 (0.0000)		4.01 (0.01)	-0.0001 (0.0000)		

(Continued)

**Table 2** (Continued)

Measurement	Time	Denture (case group) patients			Nondenture (control group) patients			Normal values
		Mean (SE)	Slope (SE)	p-Value	Mean (SE)	Slope (SE)	p-Value	
BUN	Pre	15.86 (0.19)	0.0016 (0.0008)	0.348	16.17 (0.15)	0.0010 (0.0004)	0.994	7-21 mg/dL
	Post	16.48 (0.16)	0.0010 (0.0004)		16.85 (0.15)	0.0013 (0.0003)		
Serum creatinine	Pre	1.06 (0.02)	0.0002 (0.0001)	<.001*	1.02 (0.01)	0.0001 (0.0000)	<0.001*	Male: 0.9-1.3 mg/dL Women: 0.6-1.1 mg/dL
	Post	1.06 (0.02)	-0.0001 (0.0000)		1.04 (0.01)	0.0000 (0.0000)		
eGFR	Pre	73.34 (0.48)	-0.0033 (0.0014)	0.238	76.44 (0.42)	-0.0022 (0.0008)	0.433	Healthy: >90 mL/min Kidney disease: <60 mL/min Kidney failure: ≤15 mL/min
	Post	72.06 (0.43)	-0.0014 (0.0007)		75.50 (0.41)	-0.0016 (0.0007)		
Hb	Pre	13.23 (0.04)	-0.0008 (0.0001)	<.001*	13.27 (0.03)	-0.0006 (0.0001)	<0.001*	12-16 g/dL (women) 14-17.4 g/dL (men)
	Post	13.06 (0.04)	0.0000 (0.0001)		13.19 (0.03)	0.0002 (0.0001)		
Serum calcium	Pre	9.31 (0.01)	0.0000 (0.0000)	0.039*	9.31 (0.01)	-0.0001 (0.0000)	0.001*	8.5-10.3 mg/dL
	Post	9.26 (0.01)	-0.0001 (0.0000)		9.25 (0.01)	0.0000 (0.0000)		
Serum protein	Pre	7.19 (0.01)	-0.0001 (0.0000)	0.750	7.24 (0.01)	0.0000 (0.0000)	0.061	6-8 g/dL
	Post	7.26 (0.02)	-0.0001 (0.0001)		7.24 (0.01)	-0.0001 (0.0000)		
TSH	Pre	2.38 (0.17)	0.0009 (0.0011)	0.488	2.36 (0.08)	0.0003 (0.0003)	0.697	0.4-4.0 per mU/L
	Post	2.55 (0.14)	0.0000 (0.0005)		2.56 (0.09)	0.0002 (0.0003)		

\*Indicates statistical significance; Weight (in kg); body mass index (BMI); high density lipoprotein (HDL); low density lipoprotein (LDL); total cholesterol, Triglyceride (TGL); serum albumin, blood urea nitrogen (BUN); serum creatinine; extra glomerular filtration rate (eGFR); hemoglobin (Hb); serum calcium; serum protein; thyroid stimulating hormone (TSH).

**Table 3** Pre-post analyses for subgroups among denture wearers based on dentition status

Measurement	Time	Completely edentulous			Edentulous either in upper or lower arch			Partially edentulous		
		Mean (SE)	Slope (SE)	p-Value	Mean (SE)	Slope (SE)	p-Value	Mean (SE)	Slope (SE)	p-Value
Weight (kg)	Pre	80.34 (0.54)	-0.0007 (0.0006)	0.745	80.87 (0.76)	-0.0011 (0.0009)	0.926	81.35 (0.66)	0.0004 (0.0006)	0.173
	Post	79.89 (0.53)	-0.0011 (0.0004)		80.40 (0.74)	-0.0009 (0.0006)		81.18 (0.65)	-0.0008 (0.0005)	
BMI	Pre	27.63 (0.17)	-0.0001 (0.0002)	0.215	28.18 (0.24)	-0.0005 (0.0003)	0.707	28.36 (0.21)	0.0002 (0.0002)	0.084
	Post	27.48 (0.17)	-0.0004 (0.0002)		28.03 (0.23)	-0.0003 (0.0002)		28.31 (0.21)	-0.0003 (0.0002)	
HDL	Pre	46.66 (0.58)	0.0041 (0.0023)	0.239	47.28 (0.83)	0.0049 (0.0032)	0.433	48.78 (0.67)	0.0000 (0.0023)	0.348
	Post	47.69 (0.49)	0.0006 (0.0011)		48.78 (0.72)	0.0019 (0.0014)		50.05 (0.61)	0.0029 (0.0010)	
LDL	Pre	101.19 (1.28)	-0.0146 (0.0057)	0.189	102.74 (1.77)	-0.0076 (0.0085)	0.476	107.05 (1.57)	-0.0068 (0.0072)	0.990
	Post	96.94 (1.10)	-0.0048 (0.0026)		100.49 (1.49)	0.0001 (0.0037)		103.91 (1.27)	-0.0064 (0.0030)	
Total Cholesterol	Pre	175.62 (1.65)	-0.0155 (0.0080)	0.212	178.59 (2.43)	-0.0054 (0.0112)	0.752	181.40 (2.11)	0.0218 (0.0100)	0.018*
	Post	170.94 (1.43)	-0.0018 (0.0040)		177.10 (1.87)	-0.0002 (0.0045)		182.13 (1.63)	-0.0074 (0.0038)	
Triglyceride	Pre	161.87 (4.66)	-0.0189 (0.0220)	0.482	158.75 (5.74)	-0.0386 (0.0260)	0.309	147.18 (4.91)	0.0398 (0.0260)	0.220
	Post	152.82 (3.73)	0.0013 (0.0094)		151.87 (4.52)	-0.0045 (0.0104)		152.95 (4.75)	-0.0019 (0.0136)	
Serum albumin	Pre	4.01 (0.02)	0.0001 (0.0001)	0.001*	4.08 (0.03)	0.0002 (0.0001)	0.121	4.12 (0.03)	-0.0001 (0.0001)	0.774
	Post	3.94 (0.02)	-0.0002 (0.0000)		4.06 (0.03)	-0.0001 (0.0001)		4.06 (0.02)	-0.0001 (0.0001)	
BUN	Pre	15.74 (0.27)	0.0037 (0.0010)	0.039*	15.73 (0.38)	0.0034 (0.0015)	0.040*	16.3 (0.35)	-0.0063 (0.0017)	<.001*
	Post	16.88 (0.24)	0.0013 (0.0005)		16.00 (0.31)	-0.0004 (0.0007)		16.11 (0.28)	0.0019 (0.0007)	

(Continued)

Table 3 (Continued)

Measurement	Time	Completely edentulous			Edentulous either in upper or lower arch			Partially edentulous		
		Mean (SE)	Slope (SE)	p-Value	Mean (SE)	Slope (SE)	p-Value	Mean (SE)	Slope (SE)	p-Value
Creatinine	Pre	1.10 (0.03)	0.0005 (0.0001)	<.001*	1.01 (0.03)	-0.0001 (0.0001)	0.011*	1.03 (0.03)	-0.0001 (0.0001)	0.969
	Post	1.12 (0.03)	-0.0001 (0.0000)		1.03 (0.03)	0.0001 (0.0000)		1.00 (0.03)	-0.0001 (0.0001)	
eGFR	Pre	74.16 (0.70)	-0.0082 (0.0018)	0.003*	69.92 (0.95)	0.0060 (0.0029)	0.008*	74.33 (0.87)	0.0011 (0.0027)	0.665
	Post	71.96 (0.64)	-0.0012 (0.0011)		70.03 (0.82)	-0.0032 (0.0014)		73.88 (0.77)	-0.0006 (0.0013)	
Hb	Pre	13.19 (0.06)	-0.0012 (0.0002)	<.001*	13.16 (0.09)	0.0000 (0.0003)	0.951	13.35 (0.08)	-0.0001 (0.0003)	0.963
	Post	12.96 (0.05)	0.0001 (0.0001)		13.05 (0.07)	-0.0001 (0.0002)		13.24 (0.06)	-0.0001 (0.0001)	
Serum Calcium	Pre	9.27 (0.02)	0.0000 (0.0001)	0.415	9.33 (0.02)*	0.0002 (0.0001)	0.016*	9.37 (0.02)	0.0000 (0.0001)	0.384
	Post	9.21 (0.01)	-0.0001 (0.0000)		9.29 (0.02)	-0.0001 (0.0000)		9.32 (0.02)	-0.0001 (0.0000)	
Serum Protein	Pre	7.29 (0.02)	-0.0002 (0.0001)	0.343	7.20 (0.03)	0.0001 (0.0002)	0.404	7.26 (0.03)	0.0000 (0.0001)	0.793
	Post	7.20 (0.02)	-0.0001 (0.0000)		7.15 (0.03)	-0.0001 (0.0001)		7.22 (0.02)	-0.0001 (0.0001)	
TSH	Pre	2.49 (0.25)	0.0024 (0.0016)	0.132	2.39 (0.45)	0.0020 (0.0027)	0.426	2.18 (0.20)	-0.0029 (0.0011)	0.004*
	Post	2.70 (0.22)	-0.0007 (0.0008)		2.44 (0.35)	-0.0008 (0.0012)		2.33 (0.17)	0.0015 (0.0006)	

\*Indicates statistical significance; weight (in kg); body mass index (BMI); high density lipoprotein (HDL); low density lipoprotein (LDL); total cholesterol, Triglyceride (TGL); serum albumin, blood urea nitrogen (BUN); serum creatinine; extra glomerular filtration rate (eGFR); hemoglobin (Hb); serum calcium; serum protein; thyroid stimulating hormone (TSH).



( $p = 0.384$ ) patients (Table 3). Among controls, the rate of serum calcium decrease was significant during the pre-index period but did not decrease significantly during the post-index period ( $p = 0.001$ , Table 2).

Contrary to serum albumin and calcium, the slope for creatinine increased during the pre-index period but decreased during post-index ( $p < 0.001$ ) among denture wearers and did not change post-index among controls ( $p < 0.001$ ) (Table 2). Completely edentulous patients showed an increase in creatinine pre-index and decrease during post-index ( $p < 0.001$ ), and partially edentulous patients showed no significant pre- and post-index difference ( $p = 0.969$ ) (Table 3). Whereas, patients' edentulous either in the upper or lower arch ( $p = 0.011$ ) decreased slope during pre-index but increased during post-index. Regarding Hb, the slope decreased in the pre-index period and did not change significantly in the post-index ( $p < 0.001$ ) time for denture wearers and increased for controls (Table 2). Pre-post analysis of the dentition subgroups showed that Hb slope in completely edentulous patients decreased during the pre-index phase and did not decrease significantly post-index ( $p < 0.001$ ) period (Table 3). Pre- and post-index changes of Hb for edentulous either in the upper or lower arch ( $p = 0.951$ ) or with partial dentures ( $p = 0.963$ ) were not significant (Table 3).

Although the pre-post decrease of total cholesterol was not significant for denture wearers (Table 2), among partially edentulous patients, the slope ( $0.0218 \pm 0.0100$ ) increased before partial denture treatment (pre-index) and decreased ( $-0.0074 \pm 0.0038$ ) post-index ( $p = 0.018$ ) time (Table 3). The mean total cholesterol level for all denture wearers was above the upper limit (170–181 mg/dL) of the normal range (150 mg/dL) with the highest cholesterol value seen among partially edentulous patients. The rate of change (slope) in blood urea nitrogen (BUN) levels among completely edentulous ( $p = 0.039$ ) and edentulous in the upper or lower arch ( $p = 0.040$ ) patients was increasing during the pre-index phase and decreasing during the post-index phase (Table 3). However, the BUN levels were increasing in partially edentulous ( $p \leq 0.001$ ) patients during post-index. Conversely, estimated glomerular filtration rate (eGFR) in completely edentulous patients decreased pre-index and increased during post-index ( $p = 0.003$ ), but a reverse relationship was among edentulous either in upper or lower arch patients ( $p = 0.008$ ) and partially edentulous patients ( $p = 0.665$ ). TSH in partial denture patients was decreasing pre-index and increasing post-index ( $p = 0.004$ ). There was no significant change observed in some of the subgroups for anthropometric measures and nutritional biomarkers such as HDL, LDL, TGL, and serum protein. There were no significant differences based on the pre- and post-index date within any subgroup for weight, BMI, HDL, LDL, TGL, or serum protein.

A comparative analysis among denture wearers based on their classification on dentition status for denture wearers and then a comparison with controls is given in Table S5 with their "p" values. Significant differences were observed among denture wearers based on their dentition status for total cholesterol ( $p = 0.008$ ); TGL ( $p = 0.019$ ); TGL:HDL ratio ( $p = 0.030$ ); albumin ( $p = 0.030$ ), TSH ( $p = 0.034$ ), BUN, creatinine, eGFR, and Hb ( $p < 0.001$ ) (Table S5). The calculated TGL: HDL ra-

**Table 4** Comparison of denture wearers versus controls

Measurement	p-Value
Weight (kg)	0.394
BMI	0.400
HDL	0.071
LDL	0.244
Total Cholesterol	0.601
Triglyceride	0.138
Serum albumin	*0.008
BUN	0.626
Creatinine	0.349
eGFR	0.705
Hb	*0.035
Serum Calcium	*0.001
Serum Protein	*0.008
TSH	0.858

\*Indicates statistical significance; weight (in kg); body mass index (BMI); high density lipoprotein (HDL); low density lipoprotein (LDL); total cholesterol, Triglyceride (TGL); serum albumin, blood urea nitrogen (BUN); serum creatinine; extra glomerular filtration rate (eGFR); hemoglobin (Hb); serum calcium; serum protein; thyroid stimulating hormone (TSH).

tio for partially edentulous individuals increased significantly pre-index ( $p = 0.020$ ) while it did not change significantly for other subgroups.

Neither denture wearers nor controls showed any differences in the rate of change pre-index versus post-index for HDL, LDL, total cholesterol, TGL, BUN, eGFR, serum protein, or TSH levels ( $p > 0.05$ ) (Table 3). For the controls, weight ( $p = 0.003$ ) and BMI ( $p = 0.004$ ) were significantly decreasing faster during the post-index period than the pre-index period, whereas denture wearers did not show any decrease during this period (Table 3).

### Comparison of denture wearers versus controls

Table 4 depicts the significant differences between denture wearers and controls for nutritional biomarkers. Denture wearers demonstrated faster decreases in serum protein and albumin levels post-index time compared to controls ( $p = 0.008$ ). The slope of albumin increased in the pre-index period among denture wearers while it decreased in the control group. There was no significant rate of change in Hb for either denture wearers or controls during the pre-index period. While Hb level did not decrease significantly during post-index among denture wearers, it was significantly different with an increased rate of Hb level observed in the control group ( $p = 0.035$ ). Serum calcium decreased faster during the post-index period in denture wearers compared to the control group ( $p = 0.001$ ). We calculated the TGL: HDL ratio since there was no significance among denture wearers with pre- and post-index periods for the lipid panel tests. The means for the TGL: HDL ratio for pre- and post-index periods were  $3.93 \pm 0.11$  and  $3.81 \pm 0.10$  (Mean  $\pm$  SE) for denture wearers and for controls it was  $3.71 \pm 0.12$  and  $3.67 \pm 0.11$  for pre- and post-index, respectively. There were no indications of significant changes within the pre- and post-index periods and no difference in the rate of change between pre- and post-index periods (all  $p > 0.30$  for denture wearers

and  $p > 0.10$  for controls), and no significant difference in the rates of change between the denture wearers and controls ( $p = 0.28$ ).

## Discussion

This retrospective study of 10,481 patient records with matched EDR-EHR data showed a decrease in serum albumin, calcium, creatinine, and no change in Hb among denture wearers during post-index. The results from previous studies were confirmed using a large and diverse study population that reported prosthodontic patients' nutritional profiles. When comparing denture wearers and their controls, serum albumin, calcium, and total protein decreased during the post-index period among denture wearers and Hb increased among controls (Table 4). Analyses captured the change over time and the rate of change (slope) for selected nutritional biomarkers before and after the index date. Despite the decrease in serum albumin, calcium, protein, and creatinine, the mean values of hematological markers stayed within normal limits except for total cholesterol, TGL, LDL, and weight and BMI in anthropometrics. BMI was above the normal range, which further indicates that both denture wearers and controls were overweight, consistent with Indiana's population.<sup>57</sup> The results suggest that undernutrition may potentially occur even among individuals receiving prosthodontic treatment to replace missing teeth.

According to existing literature, the reason/s for the increase or decrease in change for nutritional biomarkers before and after denture treatment and the implications are not studied in detail. It should be noted that there was a higher rate of decline in serum albumin levels in completely edentulous patients compared to other groups. These lower levels of serum albumin could be due to chewing and swallowing difficulty in older denture wearing individuals, and in patients with malnutrition and chronic inflammation.<sup>14,58,59</sup> Serum albumin, a predominant protein in blood is an indicator for nutritional assessment in healthy individuals and reduced levels indicate poor health outcomes.<sup>54</sup> A systematic review showed albumin and pre-albumin being stable and decrease only in cases of severe malnutrition.<sup>54,58,60</sup> Therefore, further study is needed to determine the role of prosthodontic treatments on albumin levels.<sup>14,59</sup>

Protein is a macronutrient and is a biomarker for assessing nutritional status. Protein levels typically decrease during nutritional impairment, infection, or inflammation because these factors influence the liver's protein synthesis.<sup>54</sup> Nevertheless, serum protein levels decreased faster among denture wearers compared to controls in this study. Moreover, serum albumin, calcium, and total protein levels had a higher rate of decline among denture wearers compared to control patients indicating interrelationships between them.<sup>61</sup> Older adults with reduced protein intake are at risk for sarcopenia which can impact physical activity and lead to poor quality of life.<sup>54</sup>

Previously, studies reported lower serum calcium levels in edentulous and partially edentulous individuals.<sup>32</sup> Denture wearers reportedly had a significantly faster decline in calcium compared to controls during the post-index period (Table 4). The alveolar bone turnover rate is rapid with small changes, and it may not be necessarily related to osteoporosis.<sup>61</sup>

Reduction in serum calcium could be attributed to reduced dietary calcium intake among denture wearers relative to others. Further evaluation is needed to determine whether the serum calcium is reduced because of reduced dietary calcium and vitamin D intake or because of their edentulousness and/or the effect of inadvertent forces from the prosthesis on the alveolar bone.

Body mass index (BMI), Hb, and total cholesterol are useful biomarkers to assess nutrition among older adults.<sup>60</sup> None of the lipid markers in the lipid panel test in the study had an impact on the changes related to pre- and post-index date except for decreased total cholesterol after partial denture treatment. Although denture wearers often complain about the difficulty in chewing, there is no evidence of nutritional impairment in healthy individuals.<sup>59</sup> In this study, we did not investigate the underlying health or living conditions of the patients and the role of these factors on nutrition. Future studies should also include analysis stratified by age to study older adults aged 60 and above.

Normal Hb levels in men range from 14 to 17.4 g/dL. The mean levels reported in this study were 13 g/dL, indicating a possible disruption of nutritional balance among men in the denture wearers group. One of the significant biomarkers for malnutrition is Hb and the study participants with dentures have a comparatively lower Hb level compared to controls (Table 4). Monitoring Hb levels for denture wearers could avoid problems related to the underdiagnosis of nutritional impairment among this group.<sup>60</sup> Screening tests for anemia in completely and edentulous patients during the prosthodontic treatment planning phase could be an effective approach to identify nutritional impairment and promote oral and overall health. Future studies based on Hb levels in denture patients stratified by gender to assess nutritional imbalance is also recommended.

Creatinine is a byproduct of muscle metabolism and is proportional to lean body mass.<sup>62</sup> Our study found decreased serum creatinine levels among completely edentulous and edentulous patients either in the upper or lower arch. A possible explanation can be attributed to the reduced intake of protein in patients wearing removable oral prostheses. Similarly, BUN and eGFR were decreased in patients edentulous either in the upper or lower arch showing an interrelationship between serum creatinine, BUN, and eGFR. All these changes may be because of reduced dietary protein intake or underlying disease conditions.<sup>62,63</sup>

The study has some limitations. First, this study utilized clinical data entered in the EHR and EDR during patient care for research. Therefore, inconsistencies may exist because multiple providers record patient care information, and the data is entered for patient care and not for research. Nevertheless, the clinical data offer the opportunity to study patient populations who received care in real-world clinical settings in contrast to randomized trials where a well-defined patient population is studied for a defined time. Second, partial denture patients were not classified based on the number of teeth present (less or more than 20) or based on their presence of posterior occluding pairs of teeth. Third, although significant, the change in hematological markers remained within the normal limit ranges and therefore, indicates the need to quantify

biologically active components of the mentioned nutritional biomarkers. For example, endogenous metabolites revealed through omics technological approaches are promising in the study of nutritional biomarkers.<sup>64</sup> In addition, factors that may influence nutritional biomarkers such as dietary supplements, medications, health conditions, inflammatory states, hormonal factors were not considered.<sup>54,64</sup> Finally, this study used patient data from one academic institution. Also, the study cohort included varied age groups, indicating a possibility of varied food consumption habits and living conditions affecting their nutrition. Multisite studies, investigating nutritional profiles of older adults, are warranted to expand the study's findings.

Despite the limitations, this study has several strengths. The study demonstrated the potential of using hematological and anthropometric values from laboratory reports to monitor nutritional biomarkers among denture wearing population. The study supports previous findings of a decline in the nutritional profile of denture wearers using a large and diverse cohort of the study population. For instance, all patients irrespective of their underlying health conditions were included. Whereas in previous clinical trials, recruited patient populations did not include patients with cognitive decline, chronic diseases, and other systemic conditions. Therefore, future studies should investigate the significance of screening patients who receive denture treatment (irrespective of the type of prosthesis they receive) for malnutrition risk using simple and easy-to-implement tools such as a questionnaire. In addition, it is also crucial that future research investigate the benefit of nutritional diet counseling for patients who receive teeth replacements—dentures as well as implants. These interventions would require communication and collaboration between dental and medical providers such as primary care physicians and dietitians to maintain the overall health of the adult denture wearing populations. The study also highlights the effect of oral health treatments on overall health. With the rising awareness to integrate dental and medical care, matched EDR-EHR data is a rich resource to study the effect of oral health and dental treatments on overall health and vice versa. Such a dataset will have a cohort with various ethnicities, and large sample size, and the generalizability of the results.<sup>65–68</sup>

## Conclusions

Use of matched EDR-EHR data assisted with evaluating nutritional biomarkers through laboratory reports and determining the nutritional profile of denture patients. Incorporating diet and nutritional counseling in addition to general post-operative instructions at the time of denture insertion has the potential to improve the oral and overall health of denture wearers. Serological tests from EHR demonstrated the potential to monitor denture wearers' nutritional status. The decreasing trend of specific nutritional biomarker values observed in the study may have an impact on oral and overall health over time in an individual's life and warrants detailed investigation. The study also reports the significance of utilizing matched dental and medical electronic records and the critical role the matched data plays in dentistry's contribution towards improving overall health.

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## Conflict of interest statement

The authors do not have any conflict of interest in regards to the current study.

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## Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table S1 List of CDT\* codes used to identify study cohort of denture wearers \*American Dental Association (ADA) CDT (Code on dental procedure and nomenclature, 2015).

Table S2 Distribution of prosthodontic procedures and procedural codes for 3,519 patients in the case (denture wearers) group.

Table S3 Demographic characteristics of 3,519 denture wearers based on dentition status. (Asterisk \* indicates significance).

Table S4: Distribution of pre-post measurements for denture wearers and control group (Asterisk \* indicates significance; \*Body mass index (BMI); High density lipoprotein (HDL); Low density lipoprotein (LDL); Total cholesterol, Triglyceride (TGL); Blood urea nitrogen (BUN); extra glomerular filtration rate (eGFR); Thyroid Stimulating hormone (TSH).

Table S5 Comparison between denture types among denture wearers as well differences between denture and nondenture wearers (Asterisk \* indicates significance; \*Body mass index (BMI); High density lipoprotein (HDL); Low density lipoprotein (LDL); Total cholesterol, Triglyceride (TGL); Blood urea nitrogen (BUN); extra glomerular filtration rate (eGFR), Thyroid stimulating hormone (TSH).