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Brazilian dentistry research productivity: state level socioeconomic, educational and structural factors

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Aim: To explore socioeconomic, educational and research factors associated with dental research productivity at the state level in Brazil. **Methods:** The authors used the Scopus database to identify dental articles published from 2006 to 2016 associated with Brazilian universities at the state level. Several social, economic, educational and research structure variables were obtained from the census and National Research Council to predict the rate of articles per 100 thousand inhabitants among the 27 Brazilian states. Rates were fitted in linear weighted least-squared regression with stepwise technique. Twenty-two variables were grouped in six blocks (social, economic, general education, dental education, research workforce and structure). **Results:** A total of 21189 articles were published, and the state of São Paulo accounted for 46%, followed by Rio Grande do Sul with 9.4%; four states did not publish any articles. There were an average (± standard deviation) of 2.6 (±1.98) published articles per 100 researchers and 13.4 (±9.6) articles per 100 thousand inhabitants. Research structure and workforce explained 92.4% and 87.2% of state variability, respectively, while the final model explained 94.5%. One extra PhD and one extra undergraduate researcher per 100 thousand inhabitants were associated with 11.3 more and 3.5 fewer articles, respectively, while every 10 points (range 0-100) on the Human Development Index (Education Component) was associated with 3.3 more articles. **Conclusion:** State scientific output has several associated factors, but research workforce and general education variables seem to be good predictors. Large disparities among state research outputs have been described and must be addressed by research and development policies.

Keywords: Bibliometrics. Dentistry. Research. Science.

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Introduction

Sustainable development goals in relation to educational processes highlight the necessity of expansion in higher education and scientific programmes, especially in less developed countries[1]. One of the reasons is that investment in science and technology has long been accepted as a way to generate knowledge and a cornerstone of social and economic development[2]. Regarding investment in research and development (R&D), Brazil, an upper middle-income country, has fallen behind the average for upper income countries, with only 1.2% of gross domestic product (GDP) expenditures and 698 full-time researchers per million inhabitants[3]. On the other hand, estimates related to dental research in Brazil have been recognized as outstanding, and current Brazilian research productivity is higher than many high-income countries[4-7] as it has a strong increment since late 1990's[8].

Research productivity as an output of investments has been assessed based on the number of scientific articles. The main determinants have been studied at individual (researcher) and institutional/organizational levels[9]. For example, male researchers of higher rank and those awarded large research grants were reported to have higher productivity in the USA[10], although younger researchers supervising graduate students tend to publish more in Saudi Arabia[11]. Also, higher education institutions (HEI) have pivotal roles, as they account for 23.7% of R&D expenditure and 64.3% of all scientific publications[2]. An important fraction of research from HEI comes from graduate programs; hence, it is not surprising that the ratio of graduate students to staff has been described as an important factor for departmental productivity[12]. Few studies have assessed the impact of undergraduate students in these figures; however results show some effect on faculty productivity[13]. On a macro-level, GDP has also been associated with performance[14] and productivity, and the Human Development Index (HDI) an important predictor of country rate of article publication[7]. Although it could be hypothesised that socioeconomic factors are associated with research productivity in Brazil, it is unclear if this association will remain after controlling for direct factors such as the rate of researchers per inhabitants. In addition, no study has described this phenomenon in the Brazilian context, which will be important in explaining state differences.

In the mid-1990s, Brazil implemented an evaluation system for graduate study programs with a strong emphasis on scientific productivity in high-impact journals. This policy was proposed from a national perspective with few incentives for state-level research agencies, with some exceptions. Variability among Brazilian states has not been described or explained to the best of our knowledge. However, analysing such variability will foster equitable development and should be pursued, as the capacity to produce contextualized knowledge at local levels is key for sustainable development. In addition, taking the continental size of Brazil into consideration, understanding local/state conditions may shed some light on possible contextual predictors affecting scientific productivity elsewhere. Therefore, the objectives of this study are to explore socioeconomic, educational and specific research factors associated with state-level output for Brazilian dental research.

Materials and methods

This is an ecological study in which the units of observation were all 27 Brazilian states. The number of published articles (dependent variable) was obtained from the Scopus database, and the other 20 potential predictors were obtained from several sources. Scopus was chosen because it is used by the Brazilian Higher Education Assessment Council (CAPES) to assess institutional proposals. It also allows the identification of authors' institutional addresses, making it possible to count the number of articles per state.

Outcome Variable

The dependent variable was the rate of articles per 100 thousand inhabitants at the state level. This was established by dividing the total number of articles from each state in an 11-year-period (2006-2016) by their population according to the 2010 census. The number of publications was retrieved by combining a search strategy for dental articles with an additional search for universities with undergraduate programs in dentistry (using authors' address identification filters at Scopus). The search strategy used to identify dental articles was obtained from a previous publication[5] and is available only in the original publication. The search to identify universities was based on the names of 219 undergraduate programs available on the website of the Federal Dental Council (CFO). Universities with more than one program in the same state counted as one, because such differences are not distinguished by Scopus.

Independent Variables

Seven social and economic variables were obtained from the Instituto Brasileiro de Geografia e Estatísica and Atlas de Desenvolvimento Humano do Brasil[15]. They are based on the 2010 census data: Gini coefficient of income inequality, proportion of individuals with inadequate sanitation, proportion of individuals living in urban areas, HDI, mean per capita income, proportion of individuals living in poverty and GDP per capita. Those variables are considered distal contextual factors that may indirectly affect research productivity.

We selected five variables that represent the general and dental educational context at the state level. The mean number of years of education at the age of 18 and the education component of the HDI were obtained from Atlas de Desenvolvimento Humano do Brasil. The rate of dental schools with undergraduate programs per million inhabitants was calculated using the number of programs available from the CFO website. Two other variables were obtained from official government data (Instituto Nacional de Estudos e Pesquisas Educacionais Anísio Teixeira [INEP]) from http://inep.gov.br/enade: mean score on the national board for final-year dental students (years: 2007, 2010, 2013) and percentage of members of dental school teaching staff holding a PhD.

Finally, we collated data to calculate eight variables concerning research structure and workforce. Based on information from the Research-Groups Census (2010) for different types of researchers at the National Research Council (CNPq) website (http://dgp.cnpq.br/planotabular/index.jsp), we created eight rates per state level inhabitants: rate of PhD researchers, rate of PhD students, rate of undergraduate students in research, rate of research groups and research lines. Data from the Research-Groups Census (2010) are provided by group leaders and certified by their institutions. Data about the number of graduate programs in dentistry (master and PhD levels) for each state was obtained from the CAPES website (https://sucupira.capes.gov.br/sucupira/) and overall, there were 101 active graduate programs.

Statistical Analysis

Descriptive data on the overall profiles of articles were presented by institution, journal and country of co-authors. Bivariate analyses were presented with categorized covariates, and differences were tested using the Kruskal-Wallis non-parametric rank test. Categorization was necessary for descriptive purposes, and states were grouped in tertiles in the case of a gradient or median/specific cut-off point if the bivariate relation was non-linear.

The rate of publication was modelled using linear regression with ordinary weighted least squares by population size[16]. All 20 variables were grouped in 6 blocks (see Table 2) and modelled using a within-block stepwise forward technique, taking $p < 0.20$ as a variable to enter into the model. Those significant variables within each block were transferred to the full model, also modelled with a stepwise forward technique with $p < 0.10$ to enter into the model. This two-step approach was needed due to the high degree of collinearity among variables; the final model was evaluated based on R-squared fit index, variance inflator factor (VIF), homoscedasticity (Cook-Weisberg test for heteroscedasticity) and normality of residuals (Shapiro-Wilk test). In multiple linear regression, variables were entered into the model as continuous and non-categorized. All analyses were carried out using Stata 13.1.

Results

In an 11-year period, Brazilian dental researchers published 21189 articles indexed in the Scopus database. The state of São Paulo accounted for 46% of all articles (n = 11767), followed by Rio Grande do Sul with 9.4% (n = 2395). Four states (Acre, Roraima, Amapá and Rondônia) did not publish any articles. Overall, during the study period (2006-2016), there were an average (± standard deviation) of 2.6 (±1.98) published articles per 100 researchers and 13.4 (±9.6) articles per 100 thousand inhabitants. The state with the highest rate was São Paulo, with 28.5 articles per 100 thousand inhabitants, followed by Rio Grande do Sul (22.4), Rio Grande do Norte (15.0), Paraíba (14.9) and Paraná (14.8). Productivity per 100 researchers was highest in the Federal District with 17.1 articles per 100 researchers, followed by Mato Grosso (6.1), Ceará (3.6), Sergipe (3.3) and five states (Maranhão, Santa Catarina, Goias, Rio de Janeiro and São Paulo) with 3.1.

Articles are concentrated in a limited number of journals, institutions and co-autors' countries. The top 10 journals accounted for 24.5% of all articles published by Brazilian researchers (Table 1), and Brazilian journals summed 6 of the top 10. While the whole list reaches almost 1000 journals, about 150 journals published 80% of all papers. The top 10 institutions were associated with 80.4% of all published articles: Universidade de São Paulo published 28.2% (the three campuses cannot be distin-

Table 1. Percentages of articles published (n=21189) with at least one Brazilian author among journals indexed in Scopus between 2006 and 2016.

	Publication	
Institution	**N**	**%**
Universidade de Sao Paulo - USP	5966	28.2%
Universidade Estadual Paulista – UNESP	3114	14.7%
Universidade Estadual de Campinas	2720	12.8%
Universidade Federal do Rio de Janeiro	1029	4.9%
Universidade Federal de Minas Gerais	969	4.6%
Universidade Federal do Rio Grande do Sul	867	4.1%
Universidade Federal de Pelotas	656	3.1%
Universidade Federal de Santa Catarina	614	2.9%
Universidade Federal Fluminense	560	2.6%
Universidade Federal de Sao Paulo	546	2.6%
Subtotal	17041	80.4%
Total	21189	100.00%
Country		
United States	2229	10.5%
Italy	492	2.3%
United Kingdom	455	2.1%
Canada	437	2.1%
Germany	266	1.3%
Switzerland	255	1.2%
Spain	249	1.2%
Netherlands	203	1.0%
Sweden	169	0.8%
France	155	0.7%
Subtotal	4910	23.2%
Total	21189	100.00%
Journals		
Brazilian Dental Journal	870	4.1%
Journal Of Applied Oral Science	709	3.3%
Dental Press Journal Of Orthodontics	625	2.9%
Journal Of Endodontics	617	2.9%
Brazilian Oral Research	569	2.7%
Pesquisa Brasileira Em Odontopediatria E Clinica Integrada	401	1.9%
Brazilian Journal Of Oral Sciences	373	1.8%
American Journal Of Orthodontics And Dentofacial Orthopedics	346	1.6%
Journal Of Periodontology	344	1.6%
Operative Dentistry	344	1.6%
Subtotal	5198	24.5%
Total	21189	100.00%

guished in Scopus), followed by UNESP (the same as Universidade de São Paulo, n = 3) with 14.7% and UNICAMP with 12.8%. The top 10 co-author countries summed

Table 2. Mean rate of articles per 100 thousand inhabitant in the period of 2006-2016 among Brazilian states (n=27).

			Mean	Std. Dev.	n	p-value*
Social Indicators	Gini Coefficient	Lower level	14.47	6.93	5	0.15
		Middle level	16.92	10.35	12	
		Higher level	5.12	2.94	10	
	Proportion of people with inadequate sanitation	up to 10%	15.99	9.58	15	0.03
		11% or more	5.54	3.83	12	
	Urbanization	Lower half	5.49	4.23	13	0.07
		Upper half	16.69	9.35	14	
	IDH	Lower half	5.79	3.84	13	0.48
		Upper half	17.47	9.31	14	
Economic Indicators	Mean individual income	Lower half	5.81	3.82	13	0.51
		Upper half	17.44	9.34	14	
	Proportion of poverty	up to 10%	17.81	9.16	11	0.02
		11% or more	5.60	3.87	16	
	GDP per capita	Lower tertile	5.29	3.19	9	0.10
		Middle tertile	8.64	4.05	9	
		Highest tertile	20.03	9.02	9	
General Education	Mean number of year of education	Lower tertile	7.14	4.52	9	0.18
		Middle tertile	8.34	4.52	9	
		Highest tertile	19.88	9.95	9	
	HDI education component	Lower tertile	5.06	3.75	9	0.01
		Middle tertile	5.99	4.02	9	
		Highest tertile	18.49	8.84	9	
Dental Education	% of undergrad lectures with PhD	Lower level	5.15	4.27	9	<0.01
		Middle level	8.21	4.21	9	
		Higher level	20.18	9.28	9	
	Rate of dental schools per 1 million inhabit	<=1 school	5.67	3.09	9	0.76
		>1 school	16.93	9.48	18	
	Mean ENAD score 2007-2013	<=2 points	2.40	2.20	5	<0.01
		>2 points	13.85	9.52	22	
Research structure	Graduate programs per million inhabit	Lower tertile	6.24	5.06	9	<0.01
		Middle tertile	4.92	1.45	9	
		Highest tertile	19.34	8.45	9	
	Research groups per 100 thousand inhabit	Lower tertile	4.39	3.70	9	<0.01
		Middle tertile	6.88	3.79	9	
		Highest tertile	19.35	9.05	9	
	Research lines per 100 thousand inhabit	Lower tertile	4.65	3.78	9	<0.01
		Middle tertile	7.65	3.92	9	
		Highest tertile	21.45	8.53	9	
Research workforce	PhD Researchers per 100 thousand inhabit	Lower tertile	4.35	3.51	9	<0.01
		Middle tertile	6.28	3.15	9	
		Highest tertile	20.03	8.23	9	
	Graduate Student researchers per 100 thousand inhabit	Lower tertile	4.10	3.84	9	<0.01
		Middle tertile	4.75	1.96	9	
		Highest tertile	18.61	8.44	9	
	Undergraduate researchers per 100 thousand inhabit	Upper half	4.48	2.79	13	<0.01
		Lower half	16.15	9.34	14	
	% of researcher >50 year-old	Upper half	7.53	4.53	11	0.76
		Lower half	16.16	10.07	12	
	% of male researchers	Upper half	7.71	4.45	11	0.80
		Lower half	16.14	10.15	12	
Total			13.40	9.57	27	

* Kruskal-Wallis ranking test

23.2% out of 133 countries; the USA accounted for 10.5%, followed by Italy with 2.3% and the UK/Canada with 2.1% each.

In bivariate analysis, several variables were significantly related to state productivity and showed high degrees of correlation (Table 2 and Table 3). Nonetheless, in the final regression model, only three variables explained 94.5% of state variability (Table 4): the educational component of the HDI, rate of undergraduate students in research and rate of PhD researchers. Every 10 points in the educational component of HDI was associated with 3.3 more articles per 100 thousand inhabitants (95% confidence interval – 1.0: 5.5), while every additional PhD researcher per 100 thousand inhabitants was associated with 11.3 more articles (95% confidence interval – 8.8: 13.8), and one additional undergraduate researcher was associated with 3.5 fewer articles (95% confidence interval – 6.2: -0.7). In the final model (Table 4), no variables were heteroscedastic; the highest VIF was associated with the rate of PhDs (VIF = 4.9). Graphic analysis of residuals showed that they were normally distributed (Shapiro-Wilk test, $p = 0.06$).

Discussion

State scientific output has several associated social and economic factors, but three seem to be good predictors: rate of PhD researchers, rate of undergraduate students (involved in research) and general education level (HDI-education). In addition, our findings showed striking state disparities in total research output. Taking the size of Brazil into consideration, as this mirror other large disparities in social, economic and cultural aspects. The use of such associations is of interest to understand which factors can predict better or worse research productivity rates.

Only three variables remained in the final model, and the most influential was the rate of PhD researchers, confirming a previous study[12], followed by the educational component of HDI and rate of undergraduate students involved in research. The rate of PhD researchers was highly correlated to other variables and may have affected some of them. For example, graduate programs educate PhDs and may be indirectly responsible for their scientific output. Furthermore, the presence of a graduate program is an interesting indicator of PhD students, research grants and other resources, such as laboratory infrastructure. States with lower levels of competitiveness may fall behind and try to offset with more undergraduate researchers than expected. In contrast to our results, another study showed that undergraduate students may increase overall productivity[13]. Nonetheless, such papers may be published in journals not indexed by Scopus and thus did not appear in our work. To our knowledge, this is the first study to include social and educational indicators, with HDI-education showing a statistically significant effect. We speculate that it may have a direct effect on research productivity by boosting critical thinking in lower education, but it is also likely to be a general marker of social development and investments in education at basic and higher levels.

State disparities were found in total research output, with São Paulo having 46% of all papers, as the University of São Paulo (USP) accounts for 28% of the whole country. USP's superiority over other Brazilian institutions has also been confirmed in previ-

Table 3. Spearman correlation coefficient matrix including all variables among Brazilian states (n=27).

		V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15	V16	V17	V18	V19	V20	V21	V22
V1	Article Rate per 100 thousand/hab	1																					
V2	Gini	-0.37	1																				
V3	Inadequate Sanitation	-0.62	0.66	1																			
V4	Urbanization	0.40	-0.51	-0.70	1																		
V5	HDI	0.42	-0.63	-0.83	0.89	1																	
V6	% of Poverty	-0.48	0.72	0.86	-0.83	-0.96	1																
V7	Mean individual income	0.40	-0.61	-0.81	0.87	0.98	-0.97	1															
V8	GNP per capita	0.38	-0.54	-0.77	0.83	0.95	-0.92	0.97	1														
V9	HDI-Education	0.42	-0.63	-0.81	0.87	0.98	-0.92	0.93	0.89	1													
V10	Mean Years of Education	0.46	-0.71	-0.72	0.62	0.69	-0.70	0.61	0.52	0.73	1												
V11	Mean ENAD score	0.39	-0.21	-0.21	-0.08	-0.04	-0.04	-0.08	-0.06	-0.03	0.24	1											
V12	Rate of Dental Schools	-0.22	-0.09	-0.14	0.33	0.39	-0.34	0.41	0.40	0.32	0.19	-0.59	1										
V13	% of PhD in Undergrad programs	0.67	-0.04	-0.31	0.30	0.20	-0.24	0.18	0.15	0.19	0.30	0.54	-0.38	1									
V14	Rate of Graduate programs	0.72	-0.35	-0.38	0.22	0.12	-0.20	0.15	0.16	0.11	0.25	0.38	-0.30	0.56	1								
V15	Rate of Research Lines	0.82	-0.26	-0.42	0.17	0.15	-0.21	0.16	0.19	0.11	0.23	0.40	-0.23	0.52	0.84	1							
V16	Rate of Research Groups	0.79	-0.29	-0.48	0.27	0.21	-0.26	0.21	0.22	0.15	0.29	0.40	-0.18	0.50	0.77	0.93	1						
V17	Rate of Researchers (total)	0.82	-0.26	-0.42	0.17	0.15	-0.21	0.16	0.19	0.11	0.23	0.40	-0.23	0.52	0.84	1.00	0.93	1					
V18	Rate of PhD Researchers	0.86	-0.39	-0.51	0.27	0.24	-0.34	0.26	0.26	0.22	0.30	0.54	-0.35	0.66	0.89	0.94	0.87	0.94	1				
V19	Rate of Undergraduate Researchers	0.76	-0.15	-0.32	0.14	0.01	-0.11	0.04	0.02	-0.04	0.15	0.46	-0.31	0.57	0.77	0.85	0.90	0.85	0.84	1			
V20	Rate of PhD Students	0.85	-0.47	-0.56	0.36	0.34	-0.40	0.32	0.29	0.32	0.41	0.53	-0.33	0.61	0.77	0.87	0.87	0.87	0.92	0.84	1		
V21	% of Male Researchers	-0.10	-0.36	-0.10	0.09	-0.01	-0.01	-0.02	0.01	-0.06	0.07	-0.04	-0.10	-0.16	0.31	0.03	0.19	0.03	0.06	0.15	0.04	1	
V22	% of Senior Researchers	0.00	-0.15	-0.20	0.24	0.08	-0.13	0.12	0.15	0.06	-0.03	0.26	-0.31	0.20	0.33	0.24	0.31	0.24	0.41	0.30	0.34	0.39	1

NOTE: in shade coefficients of variables related to same theoretical block

Table 4. Coefficients from linear regression models of articles per 100 000/inhabitants among Brazilian States (n=27), 2006-2016.

Block	Variable	Within block stepwise* regression			Final Model stepwise* regression		
		coefficient	(IC95%)	adjusted R2	coefficient	(IC95%)	adjusted R2
Social Indicators	HDI** (every 10 points increase)	14.2	(9.5 : 19.0)	58.6%			94.5%
Economic Indicators	Mean individual income (every R$1000 increase)	25.8	(16.4 : 35.1)	54.4%			
General Education indicators	HDI** education component (every 10 points increase)	11.9	(8.2 : 15.5)	62.4%	3.3	(1.0 : 5.5)	
Dental Education Indicators	% of undergrad lectures with PhD (every 10 percent points increase)	7.1	(5.1 - 9.1)	76.8%			
	Rate of dental schools per 1 million inhabit (>1 school)	9.2	(5.2 : 13.2)				
Research structure indicators	Research groups per 100 thousand inhabit (every one more)	35.0	(20.4 - 49.6)	87.2%			
	Graduate programs per 1 million inhabit (every one more)	8.4	(1.1 : 15.8)				
Research workforce	PhD Researchers per 100 thousand inhabit (every one more)	14.2	(12.1 : 16.2)	92.4%	11.3	(8.8 : 13.8)	
	Undergraduate researchers per 100 thousand inhabit (every one more)	-5.7	(-8.5 : -2.9)		-3.5	(-6.2 : -0.7)	

* forward stepwise regression with entry value p<0.10 (ordinary weighted least-squares by population size)
** HDI=Human Development Index varies from 0 to 100.

ous studies[5,17], and it has been estimated to contribute more than 20% in all research areas[18]. Indeed, São Paulo is the only state in Brazil where the dentistry field is the most productive in all research fields in Brazil[18]; therefore, state differences are likely to be larger in dentistry than other areas. A similar concentration of publications in a few places has been reported in the African continent, where Nigeria and South Africa account for over two-thirds of all oral health-related research[19]. On one hand, São Paulo has the highest percentage of investments in R&D regarding GDP[20], the São Paulo Research Foundation (FAPESP) plays an important traditional role[21]. On the other hand, there seems to be a trend to decentralize researchers, relocating them to other areas of Brazil from São Paulo[22]. Although the role of national R&D agencies in compensating regional disparities is not clear from our study, the concentration of graduate programmes in the southeast declined from 73% to 51% between 1980 and 2010 as part of the CAPES policy[23]. That policy increased the number of graduate programs in other regions, decreasing the share of programs in already developed areas.

One important aspect is that the regulatory system of evaluating higher education in Brazil likely triggers of the development of scientific communication and dissemination; the field of dentistry is an example. Our analysis shows a steep increase in publications in high-impact journals (data not shown). Over the period observed, the increase was not uniform countrywide; social, economic and cultural variables probably accounted for the differences. The increase in funding in R&D must also explain part of the increase in productivity in the last decades. The present study confirms the virtuous cycle of investment and development output. In addition, the association between the increase in PhDs among teaching staff in dental education and better research output should be highlighted. The results encountered herein should encompass the increase in dental programs in states where there were few or none.

A limitation of this study is the use of university names as surrogates for states. There may be other institutions contributing scientific output that were not included, although we have no reason to think our conclusions would be different in that case, as very few papers would be lost. A second point concerns the quality of the data, a common issue in ecological studies, as validity and reliability are usually lower when information is not designed for scientific purposes. Data from CNPq and other sources are administrative in nature with some degree of measurement error. Nonetheless, we believe that such measurement errors are likely to be random and do not invalidate our findings. Another limitation is that our study cannot identify inter-state institutional collaboration; this would require a different approach to find all authors' addresses. The strengths of this work include the large geographical coverage and a search strategy with good sensitivity and specificity[5]. The generalization of our results is limited to Brazilian scenarios but may hold true for other countries with similar contexts.

In conclusion, this study demonstrates the role of important factors associated with dental research productivity at the state level in Brazil. The rate of researchers, the most influential variable, is likely to be a consequence of other structural determinants of research productivity. State disparities were found not only in total output but also in per capita productivity. This research may assist agencies and researchers to better understand macro-determinants of scientific research and foster future policies.

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