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Predicting intention of Norwegian dental health-care workers to use nanomaterials: An application of the augmented theory of planned behavior

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Abstract
Due to the rapid development of nanotechnology and its integration into dentistry, there is a need for information on the factors influencing the decision of dental health-care workers to use nanomaterials. Based on a national survey among Norwegian dentists and dental hygienists, this study applied the theory of planned behavior (TPB), augmented with past behavior and perceived risk, to predict the intention to use dental nanomaterials in the future and to assess whether an augmented TPB model operates equivalently across professional groups. Structural equation modelling was used to assess whether the hypothesized model fits the data. Of 1792 eligible participants, 851 responded to an electronic survey. Attitudes and perceived behavioral control had the strongest effect on intention, followed by past behavior and subjective norms. Risk perceptions had an indirect effect on intention. Multigroup comparison confirmed invariance of the model across professional groups. This study supports the validity of the augmented TPB model to explain the intention of Norwegian dentists and dental hygienists to use nanomaterials. The strongest influence on intention is given by the attitudes toward nanomaterials and perceived confidence in their use. The findings of the study have implications for management of the use of nanomaterials in dentistry by policy makers.

KEYWORDS
attitudes, behavioral research, dental nanomaterials, intentions, structural equation modelling

INTRODUCTION

Nanotechnology is one of the essential technologies of the 21st century [1]. It involves the use of nanomaterials, which are defined as 'natural, incidental, or manufactured materials containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50% or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm–100 nm' [2]. As a result of the unique properties of nanoparticles, nanotechnology has become a promising field that has improved many aspects of human life. However, nanoparticles may also exhibit toxic effects and this raises concerns about possible health and environmental risks [3]. A significant body of research has focused on the unique properties of nanoparticles, their toxicological aspects [4, 5] and the development of reliable tools for assessment of nanotoxicity [6, 7]. By contrast, relatively little research has been carried out regarding the opinions of stakeholders and the general public on nanotechnology and the intention to use innovative materials.

Studies from Europe and the United States have demonstrated that the general public is rather unfamiliar with the topic of nanomaterials [8–11] and that their attitudes toward nanotechnology are either positive or neutral [8, 11, 12]. Moreover, there is evidence indicating that risk perceptions related to nanotechnology are higher among laypersons than among nanotechnology experts, policy makers, and risk managers [9, 10, 13–15]. However, possible environmental pollution and long-term health problems associated with nanotechnology, as well as use of nanomaterials in food, cosmetics, and packaging, have raised higher concerns among scientists than among non-experts [14, 15]. Interestingly, a recent study revealed that nano-scientists and engineers perceive lower risk than the experts involved in risk regulation and management [16]. Considering that nanotechnology is a relatively new and continuously developing field, the opinions of stakeholders and the general public have not been completely established and thus might change in pace with accumulation of new knowledge [14].

Dentistry is among the fields that have been significantly improved by nanotechnology [17]. The current market offers a variety of dental materials modified by nanoparticles, such as restorative composites, glass ionomer cements, adhesives, and bone-regenerative materials, to name but a few [18–20]. Recently, it has been demonstrated that dentists and dental hygienists have moderate knowledge about nanomaterials and perceive both risks and benefits related to their application [21]. Although several studies have reported on public and expert opinion about nanotechnology, few studies have investigated the attitudes of dental health-care professionals toward this technology [8–16]. Thus, our understanding of the reasons why dental health-care workers use or refrain from use of nanomaterials in the context of clinical dental care is incomplete. Investigation of the attitudes of dental health-care workers towards nanomaterials is essential because it plays an important role in their acceptance or rejection of nanotechnology [22, 23]. To assist policy makers in their management practice, we need to identify the psychosocial factors that influence the decision of dental health-care workers on whether or not to use nanomaterials when treating patients in the future.

The theory of planned behavior (TPB) is a well-recognized theoretical framework of the attitude–behavior relationship, which assumes that most conscious behaviors are goal directed [24]. This theory is an extension of the theory of reasoned action (TRA) and has been applied across various populations, contexts, and behavioral domains [25–31]. In addition to the TRA constructs, the TPB includes perceived behavioral control, therefore allowing a better explanation of behaviors which are beyond full volitional control and improved predictive power of the model [24, 32]. Moreover,TPB has proved to be a reliable tool in predicting and explaining occupational behaviors [26, 30, 31, 33–36]. A systematic review revealed consistency of predicted behavior between health-care professionals and non–health-care professionals, indicating that TPB is a valid tool for use in the occupational context of health care [26]. Meta-analyses have shown that the TPB explains (on average) 39%–59% of the variance in behavioral intention, whereas intention explains (on average) 19%–35% of the variance in actual behavior [30, 37, 38].

According to the TPB, behavior is predicted by behavioral intention (summarizing a person's motivation to engage in a particular behavior and indicating how hard the person is willing to try and how much time and effort he or she is willing to devote in order to perform the behavior) and perceived behavioral control (perception of presence or absence of necessary resources and opportunities as well as anticipated obstacles or impediments related to performing the behavior). Intention, in turn, is a joint function of perceived behavioral control, attitudes toward performing the behavior (positive or negative evaluation of the behavior), and subjective norms (perceived social pressure of performing or not performing the behavior). The TPB maintains that the relative importance of the TPB constructs differs according to the particular behavior and populations investigated [32].

As proposed by Ajzen [32], the original TPB model can be augmented by external variables, such as demographics, moral norms, descriptive norms, and anticipated regret, in accordance with the context and nature of the particular behavior investigated [25, 30, 39]. A number of studies have reported on residual effects of past behavior on intention and future behavior after having controlled for the original TPB constructs, suggesting that these effects reflect the sufficiency of the TPB model [40, 41]. Only a few studies have considered the occupational behavior of dental health-care professionals using a socio-cognitive approach [33, 34, 36, 42, 43].

Whereas knowledge was demonstrated to be an important covariate of the risk perceptions of dental health-care workers related to use of nanomaterials[21], a socio-cognitive model to explain variance in intention to use these materials has yet to be validated among dentists and dental hygienists employed in the public dental health-care service in Norway. As dental health-care workers have been using dental nanomaterials for patient treatment, it seems relevant to investigate whether past behavior predicts the intention to use nanomaterials beyond the effect of the original TPB constructs. In addition, risk perceptions related to nanomaterials might influence behavioral intention, as demonstrated by previous studies

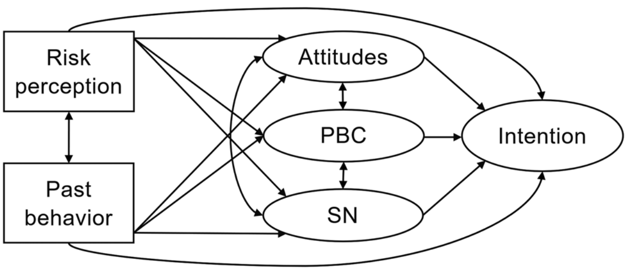

FIGURE 1 The hypothesized augmented theory of planned behavior (TPB) model including four latent variables (intention, attitudes, perceived behavioral control [PBC], and subjective norms [SN]) and two observed variables (risk perception and past behavior)

[27–29]. Relying on the TPB augmented with past behavior and risk perception, the purpose of this study was to predict the intention of dental health-care workers to use nanomaterials in the future and to explore whether the augmented TPB model operates equivalently across the professional groups of dentists and dental hygienists. In accordance with TPB, it was hypothesized that positive attitudes toward the use of dental nanomaterials, stronger confidence in the ability to use these materials (perceived behavioral control), and higher pressure from significant others (subjective norms) increase the intention to use dental nanomaterials. Furthermore, it was suggested that external variables, in terms of risk perception and previous experience with nanomaterials (past behavior), have both direct and indirect effects on behavioral intention, through attitudes, subjective norms, and perceived behavioral control. The hypothesized model for the present study is depicted in Figure 1.

MATERIAL AND METHODS

A census of all dentists and dental hygienists working in the public dental health-care service in Norway (1792 eligible participants) was asked to participate in a cross-sectional self-administered survey in March–May 2017. The questionnaire was developed based on recommendations for TPB questionnaires and relevant literature [44] and was pilot-tested in a public dental clinic in Bergen. The Norwegian Centre for Research Data approved the survey (51053/3/AMS) and was responsible for administration of the questionnaire, data collection, and anonymization of personal information about participants. The questionnaire, together with the informed consent and a short introductory description of nanomaterials (Appendix S1), was distributed by e-post. The main invitation to the survey was supplemented by three consequent reminders in an attempt to increase the response rate.

The questionnaire included the original constructs of the TPB: intention, attitudes, perceived behavioral control, and subjective norms. Each of the TPB constructs was measured by several items, with responses recorded on a seven-point Likert scale that ranged from '1 = strongly agree' to '7 = strongly disagree' (except for item 18 that ranged from '1 = very easy' to '5 = very difficult'). The scales of items 7, 10, and 12 were reversed as they represented negative statements (Table 1). Low scores indicated positive cognitions, and high scores indicated negative cognitions. Intention was measured by four items, three of which assessed positive intention, while the fourth asked about the likelihood of using nanomaterials in the future. Attitudes were measured by nine items: six were positively worded and three were negatively worded. Perceived behavioral control and subjective norms were measured by five and four positively phrased items, respectively. In addition, two variables, external to the TPB model, were incorporated: (1) risk perceptions of dental nanomaterials, and (2) past behavior. Risk perception was a summative score of six items, each assessed on a seven-point Likert scale that ranged from '1 = very likely' to '7 = very unlikely', for which low scores represent high perception of risk and high scores represent low perception of risk (Table 1). Past behavior was measured by one item 'Have you used dental nanomaterials for patient treatment before?' with response alternatives '1 = yes', '2 = no', and '3 = I don't know', which were further dichotomized into '0 = yes' and '1 = no/I don't know' for the purpose of analysis. In accordance with recommendations, the TPB constructs in the augmented model were measured considering the four elements of action (using), target (nanomaterials), context (for patient treatment), and time (in the future) [24].

Statistical analysis

Descriptive statistical analysis, in terms of frequencies and mean distributions, was conducted using SPSS, version 25.0 (IBM). Structural equation modelling was performed using the Lavaan package [45] in R (R Core Team). Structural equation modelling is an advanced statistical technique that enables us to investigate whether the hypothesized augmented TPB model has acceptable fit to the data, testing simultaneously the interrelationships between the constructs specified in the hypothesized model [46].

In the present study, a two-stage modelling approach was used to test the hypothesized augmented TPB model [47]. First, confirmatory factor analysis (CFA) was performed to test the factorial validity of the latent constructs and the adequacy of the measurement model. In the first stage, four latent constructs comprising the original TPB model were used (intention, attitudes, perceived behavioral control, and subjective norms), excluding risk perception and past behavior as they were used as observed variables in the model. Potential sources of misfit were examined with the help of modification indices, which provided a basis for the re-specification of the measurement model.

TABLE 1 Descriptive statistics for the theory of planned behavior (TPB) measurement model

Latent factor	Itemno.	N[a]	Question	Scale	Mean	SD
Intention; $\alpha = 0.93$						
	1	712	I intend to use dental nanomaterials for patient treatment in the future	b	3.2	1.3
	2	715	I plan to use -//-	b	3.2	1.4
	3	712	I have decided to use -//-	b	3.5	1.3
	4	718	How likely is that you will use -//-	c	2.8	1.3
Attitudes; $\alpha = 0.93$						
	5	754	To use nanomaterials for dental treatment in the future is a good idea	b	3.4	1.2
	6	751	-//- is important	b	3.4	1.2
	7[e]	749	-//- is dangerous	b	3.9	1.0
	8	734	-//- is responsible	b	3.5	1.1
	9	729	-//- is reasonable considering the quality of treatment	b	3.2	1.1
	10[e]	735	-//- is irresponsible considering the patient's health	b	3.8	1.1
	11	705	-//- is valuable	b	3.3	1.1
	12[e]	709	-//- is useless	b	3.2	1.1
	13	713	-//- is interesting	b	2.9	1.3
Perceived behavioral control; $\alpha = 0.80$						
	14	668	If I want, I have the possibility to use dental nanomaterials for patient treatment in the future	b	3.0	1.3
	15	673	It is totally up to me if I use -//-	b	3.9	1.5
	16	673	I have all the resources I need to use -//-	b	3.7	1.4
	17	669	I am sure that I am able to use -//-	b	3.2	1.3
	18	672	How easy or difficult you think it is to use -//-	d	2.7	0.7
Subjective norms; $\alpha = 0.87$						
	19	661	Colleagues who influence my clinical practice think that I should use dental nanomaterials for patient treatment in the future	b	3.9	1.2
	20	661	Colleagues who are important to me think that I should use -//-	b	3.8	1.2
	21	655	The chief dentist of my clinic thinks that I should use -//-	b	3.9	1.1
	22	659	The chief dentist of the county thinks that I should use -//-	b	3.8	1.0
Risk perception[f]; $\alpha = 0.89$						
	23	660	How likely is that you subject yourself to health damage by using dental nanomaterials in the future	c	3.9	1.1
	24	657	How likely is that you increase your own risk to get cancer by using -//-	c	4.0	1.1
	25	658	How likely is that you inhale nanoparticles that accumulate in your body if you use -//-	c	3.7	1.2
	26	647	How likely is that you contribute to the uncontrolled spreading of nanoparticles if you use -//-	c	3.6	1.2
	27	649	How likely is that you contribute to patient's health damage if you use -//-	c	4.1	1.1
	28	646	How likely is that you contribute to environmental pollution if you use -//-	c	3.4	1.3

[a]Number of participants does not add up to 851 in the questions because of missing values (11%–24% in separate items).
[b]7-point Likert scale ranging from 1 (strongly agree) to 7 (strongly disagree).
[c]7-point Likert scale ranging from 1 (very likely) to 7 (very unlikely).
[d]5-point Likert scale ranging from 1 (very easy) to 5 (very difficult).
[e]Scale of items 7, 10, and 12 was reversed as they represent negative statements.
[f]Risk perception is a summative score (range 6–42), incorporated as an observed variable in the structural equation model.

Second, following the specification of the measurement model, structural equation modelling was performed to examine whether the hypothesized augmented TPB model has acceptable fit to the data and to estimate direct, indirect, and total effects of relationships in the model. The following statistical parameters were used to measure how well the hypothesized model fit the data – chi-square (χ^2) test, comparative fit index (CFI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR) [48]. A statistically non-significant chi-square test result (i.e., $P > 0.05$) indicates good fit of the model. However, because this test is highly sample-size sensitive (large samples can lead to a significant *P*-value of the chi-square test, even with trivial misspecifications), the emphasis was set on the remaining fit indices. In line with conventional recommendations of Hu and Bentler [49], values of CFI > 0.90 and > 0.95, of RMSEA < 0.08 and < 0.06, and of SRMR < 0.08 and < 0.05 indicate acceptable fit and good fit, respectively. The maximum likelihood estimator with robust standard errors was applied to account for non-normally distributed data. Missing data were handled by the full information maximum likelihood, which is most often superior to handling missing data by use of standard ad hoc routines, such as mean replacement and listwise or pairwise deletion [50].

Multigroup analyses were performed with CFA and structural equation modelling to test whether the model was invariant across the two groups of employees. Before investigating the invariance of predictive paths (using structural equation modelling), the configural and metric invariance was assessed in the final measurement model (using CFA). The configural invariance (equal forms) was tested by fitting the final measurement model across dentist and dental hygienists. Configural invariance was supported if the model had a satisfactory fit (based on the above-mentioned fit indices). Metric invariance (equal factor loadings) was tested by constraining factor loadings in both groups and by comparing the constrained model with the baseline model (configural invariance model) in which factor loadings were free to vary. Metric invariance was supported if the chi-square change was non-significant and the CFI change was less than 0.002 [51]. Invariance of predictive paths was tested by comparing a structural equation model in which both factor loadings and regression paths were constrained across the groups with a baseline structural equation model in which factor loadings were constrained and regression paths were free to vary. The criteria for invariance of predictive paths were insignificant chi-square change and CFI change less than 0.002.

RESULTS

A total of 851 participants responded to our survey (response rate 47.5%). Descriptive statistics of all variables measuring the TPB constructs and risk perceptions are presented in Table 1. As reflected by mean values of item score measuring different constructs, participants exhibited the following: moderate-to-strong intention to use nanomaterials; somewhat positive attitudes; slightly positive perceived behavioral control and subjective norms; and moderate risk perceptions. Cronbach's alpha values ranged from 0.80 for perceived behavioral control to 0.93 for intention and attitudes, indicating high internal consistency.

Table 2 depicts sociodemographic characteristics stratified according to professional status. In line with the gender and professional distribution in the census of Norwegian dental health-care workers in the public dental healthcare service, 18.6% were male and 71.0% were dentists. The mean ± SD age of the participants was 41.5 ± 11.9 years. Of all respondents, 54.0% (63.7% dentists and 28.7% dental hygienists) confirmed that they had previously used dental nanomaterials.

Measurement model

Standardized factor loadings of all items were significant ($P < 0.001$) and ranged from 0.385 to 0.948 (results not shown). Standardized correlation coefficients ranged from 0.444 to 0.782 and were below the cut-off point of 0.85 (results not shown), indicating satisfactory discriminant validity of the latent constructs in the model [52].

The hypothesized correlated four-factor model approached acceptable fit, as indicated by fit indices (Table 3, Model 1). According to modification indices, the model fit could be improved by allowing correlation between residuals of items in the attitude construct (item 5 with item 6, item 7 with item 10) and in the subjective norms construct (item 21 with item 22) (Table 1). These residual correlations made theoretical sense and were therefore added to the model, one by one (Model 2 – Model 4). The final measurement model thus achieved a good fit (Table 3, Model 4).

Model 4 had an acceptable fit when applied separately for dentists ($\chi^2 = 522.9$; df = 200, $P < 0.001$, CFI = 0.947, RMSEA = 0.063 (90% CI = 0.057–0.070), SRMR = 0.048) and dental hygienists ($\chi^2 = 285.7$; df = 200, $P < 0.001$, CFI = 0.946, RMSEA = 0.058 (90% CI = 0.42–0.73), SRMR = 0.062). Configural invariance was supported as Model 4 fitted the data well across the two groups of dentists and dental hygienists ($\chi^2 = 788.4$ (df = 400), $P < 0.001$, CFI = 0.947, RMSEA = 0.062 (90% CI = 0.055–0.068), SRMR = 0.051). Metric invariance was also achieved as $\Delta\chi^2 = 0.655$ (df = 400–418, $P > 0.05$) and ΔCFI = 0.000.

Structural model

The full structural model had a good fit (Table 3, Model 5). All direct and indirect effects were in the expected direction. Within the model, all the hypothesized effects were

TABLE 2 Sociodemographic factors stratified according to professional status in the total sample

Factor	Dentist $n = 570$ % (n)	Dental hygienist $n = 228$ % (n)	Total $n = 798$[a], % (n)
Gender**			
Male	25.6 (139)	1.4 (3)	18.6 (142)
Female	74.4 (404)	98.6 (218)	81.4 (622)
Work experience*			
≤ 5 years	28.2 (161)	19.3 (44)	25.7 (205)
6–20 years	44.7 (255)	43.4 (99)	44.4 (354)
> 20 years	27.0 (154)	37.3 (85)	29.9 (239)
Place of education**			
Norwegian institution	68.7 (389)	96.5 (220)	76.7 (609)
Foreign institution	31.3 (177)	3.5 (8)	23.3 (185)
County region[ns]			
South-East	40.9 (233)	42.7 (97)	41.4 (330)
West	30.2 (172)	24.7 (56)	28.6 (228)
Middle-North	28.9 (165)	32.6 (74)	30.0 (239)
Past behavior**			
Yes	63.7 (311)	28.7 (54)	54 (365)
No/I don't know	36.3 (177)	71.3 (134)	46 (311)

[a]Number of participants is not 851 in each question because of missing values.
Testing the association between factor and professional status: [ns], not significant; *$P < 0.05$; **$P < 0.001$.

TABLE 3 Overall goodness-of-fit indices for the theory of planned behavior (TPB) measurement models (Models 1–4) and full structural model (Model 5)

Fit indices	Model 1	Model 2	Model 3	Model 4	Model 5
χ^2	782.3	680.6	612.8	555.9	665.5
df	203, $P < 0.001$	202, $P < 0.001$	201, $P < 0.001$	200, $P < 0.001$	236, $P < 0.001$
CFI	0.926	0.940	0.948	0.956	0.946
RMSEA	0.075	0.068	0.063	0.058	0.063
90% CI RMSEA	0.069–0.080	0.062–0.074	0.057–0.069	0.053–0.064	0.058–0.069
SRMR	0.049	0.048	0.045	0.042	0.045

Abbreviations: χ^2, chi-square test; df, degrees of freedom; CFI, comparative fit index; RMSEA, root mean square error of approximation; SRMR, standardized root mean square residual.

significant, except the direct effect of perceived risk on intention and indirect effect of perceived risk on intention through subjective norms (Table 4). Attitudes ($\beta = 0.53$, $P < 0.001$) and perceived behavioral control ($\beta = 0.24$, $P < 0.001$) were the strongest predictors of intention, followed in descending order by past behavior and subjective norms. Risk perception had a significant indirect effect on intention through attitudes and perceived behavioral control. Past behavior associated positively and directly with behavioral intention as well as indirectly through positive associations with attitudes, perceived behavioral control, and subjective norms. The total effect (indirect and direct) of risk perception on intention was negative ($\beta = -0.21$, $P < 0.001$), while the total effect of past behavior was positive ($\beta = 0.53$, $P < 0.001$). The augmented TPB explained, as expressed by R-squared, 74.5% of the variance in intention to use dental nanomaterials in comparison with the original TPB (attitudes, perceived behavioral control and subjective norms) that explained 71.8%. Multigroup analysis revealed that the fit of the model where regression paths were constrained was not significantly worse than the fit of the model where regression paths were free to vary ($\Delta\chi^2 = 0.32$; df = 490–501, $P > 0.05$; ΔCFI = 0.000). This confirms that regression paths were invariant across the two professional groups investigated.

DISCUSSION

The present study explains, using the TPB augmented with risk perception and past behavior, the intention of dental health-care workers to use nanomaterials in future treatment of patients. Although the direct effect of risk perception on

TABLE 4 Estimated standardized coefficients for the structural equation model (Model 5), showing the mediating effects between included variables

Direct effects	β	95% CI
Intention		
Attitudes (a)	0.53**	0.44 to 0.62
PBC (b)	0.24**	0.12 to 0.36
SN (c)	0.11*	0.04 to 0.18
Risk[a] (d)	0.00ns	−0.05 to 0.05
PB (e)	0.15**	0.09 to 0.21
Attitudes		
Risk (f)	−0.26**	−0.36 to −0.20
PB (i)	0.40**	0.34 to 0.47
PBC		
Risk (g)	−0.24**	−0.33 to −0.16
PB (j)	0.54**	0.48 to 0.59
SN		
Risk (h)	−0.03ns	−0.13 to 0.07
PB (k)	0.38**	0.31 to 0.44
Indirect effects		
a*f: Risk→Attitudes→Intention	−0.15**	−0.20 to −0.09
b*g: Risk→PBC→Intention	−0.06**	−0.09 to −0.02
c*h: Risk→SN→Intention	−0.01ns	−0.01 to 0.01
a*i: PB→Attitudes→Intention	0.21**	0.16 to 0.26
b*j: PB→PBC→Intention	0.13**	0.06 to 0.19
c*k: PB→SN→Intention	0.04*	0.02 to 0.07
Total effects		
Risk	−0.21**	−0.28 to −0.13
PB	0.53**	0.48 to 0.59

Abbreviations: β, standardized beta coefficient; PB, past behavior; PBC, perceived behavioral control; SN, subjective norms.

[a]'Risk' stands for 'Risk perception'.

nsNot significant.

*$P < 0.05$.

**$P < 0.001$.

intention was not confirmed in the hypothesized model, indirect effects of risk perception through attitudes and subjective norms were significant and in the expected direction. Thus, the findings confirm the structural validity of the hypothesized augmented TPB model, suggesting that this model is useful in identifying key socio-cognitive factors predicting the intention to use nanomaterials among dental health-care workers employed in the Norwegian public dental health-care service. Past behavior and risk perceptions added 2.7% to the explained variance in dental health-care workers' intention over and above that explained by the original TPB model (71.8%). The explained variance observed in this study compares with the data reported in some previous studies, whereby the TPB explained 65.0% of dentists' intention to apply fissure sealants, 69.0% of nurses' intention to recommend breastfeeding, and 77.0% of nurses' intention to accept information technologies [30, 31, 43].

One strength of the present study is the use of a census of dentists and dental hygienists working at public dental health-care service in Norway. Another strength is the use of a well-recognized theoretical framework, TPB, augmented according to the context with external variables. Moreover, structural equation modelling was employed to test the hypothesized model. This method is considered to be an advanced statistical technique that enables simultaneous testing of all relationships between both observed and latent variables in theoretical models, that would not be possible with ordinary regression analysis. Finally, high values of Cronbach's alpha indicated high internal consistency, suggesting that the items of the particular scales reflect the same underlying constructs. However, another reason for high coefficient value is the number of items measuring the construct. Specifically, attitudes were measured with nine items, which may result in an increased value of Cronbach's alpha [53].

Some limitations of this study should be addressed. Self-selection of the participants might have led to a selection bias if only those who were interested in the topic of nanotechnology or those who had some knowledge about nanomaterials replied, thus compromising the generalizability of the results. Moreover, the moderate response rate (47.5%) might also lead to limited generalizability. However, the gender and professional distribution of the respondents is consistent with that in the census of dental health-care professionals, supporting the external validity of the study. The cross-sectional nature of the data collection reflects the opinions of dental health-care workers at a particular time point, making it difficult to draw a conclusion about causal relationships. The present study did not assess actual behavior as the final outcome and in a prospective context as suggested by Ajzen [32]. Although intention is recognized to be a good proximal predictor of actual behavior, gaps between those constructs have been identified [26, 54]. Finally, the high percentage of explained variance observed in this study might reflect a problem of overfitting as a result of measuring all constructs at the same time and the problem of using self-reported data.

With regard to the relative importance of the three TPB constructs, attitude was the strongest predictor of intention to use nanomaterials followed by perceived behavioral control and normative pressure. Thus, the more favorably the use of nanomaterials was evaluated, the more confidence about managing such materials and the stronger the influence from immediate social environments, the stronger the intention among both dentists and dental hygienists. The importance of perceiving a relative advantage of using nanomaterials suggests that the decision of dental health-care workers was predominately considered as a personal choice. This finding contrasts with that reported in a review by Thompson Le-Duc [31], suggesting subjective norms to be the theory-based construct most frequently associated with health professionals' shared decision-making behaviors. Also, in contrast with The findings of a systematic review by Godin et al. [30], which included analyses of various behaviors of health professionals suggested perceived behavioral control to be the most important predictor of behavioral intention, are also in contrast to the findings of the present study. Nevertheless, Perkins et al. [35], who also examined theory-based applications, concluded that the most important TPB construct varied across groups of clinicians and different behaviors. Consistent with the present study, attitudes have been identified as an important determinant of the intention of dentists to place fissure sealants in children's teeth [43], the intention of dental health-care workers to report suspected child maltreatment [33], and the delivery of preventive messages regarding diet, alcohol, and tobacco by dentists to their patients [36].

Perceived behavioral control played an important role in explaining intention in this study and was partly a reflection of past success and failures with the performances. This suggests that the perception of facilitating factors and barriers by dental health-care workers was influential. One plausible explanation might be that clinically related decisions, such as choosing nanomaterials instead of more conventional materials, is a complex procedure that requires various resources and is impacted by several aspects of the context, such as characteristics of the actual treatment and patients' acceptability or treatment preferences. Surprisingly, subjective norms were the weakest predictor of behavioral intention in this study, indicating that opinion of the immediate social environment was less influential regarding the use of dental nanomaterials. Even though dental health-care workers had, to some extent, experience with nanomaterials and past behavior had a positive effect on subjective norms, it is possible that the morals or principles of clinical behaviors reflecting professional norms regarding nanotechnology have yet to be established among Norwegian dental health-care workers. As stated by Ajzen, subjective norms present 'no clear pattern' [32]. Several systematic reviews have confirmed weak associations between subjective norms and behavioral intention [25, 55].

Incorporation of past behavior and risk perception into the TPB model increased the explained variance of the intended use of nanomaterials. This suggests that the three theoretical constructs of TPB did not provide an accurate description of the cognitions underlying the use of nanomaterials by dental health-care workers. Dental health-care workers who have already used nanomaterials would rather continue using them in the future. Moreover, previous experience had positive effects on the TPB constructs, suggesting that participants who had used nanomaterials possessed more positive attitudes, stronger perceived control, and higher perceived societal pressure. While some researchers criticize past behavior for not having predictive power, others, on the contrary, support inclusion of this factor in the model [41]. The present study is in line with the latter opinion, suggesting that past behavior had a significant effect on intention in the context of dental nanomaterials.

In contrast to the findings from the study by Zhu [29], there was no direct relationship between risk perception and intention, suggesting that this relationship is more complicated than originally hypothesized in this study. However, risk perception had an indirect effect on intention through attitudes and perceived behavioral control, indicating that participants with low perceptions of risk had more positive attitudes and stronger perception of control over their decision to use nanomaterials, which, in turn, were associated with higher intention to use such materials.

Prospective research should target participants from different countries to test the proposed model further. More studies are needed to uncover the relationship between the risk perception of dental nanomaterials and intention to use these nanomaterials. Apart from that, subsequent behavior should be assessed by using information from dental records instead of self-reports, as utilized in the present study.

In conclusion, the results of this study support the validity of the augmented TPB model to explain the intention of Norwegian dentists and dental hygienists to use nanomaterials. The strongest influence on intention is given by the attitudes toward nanomaterials and perceived confidence regarding their use. The findings of the study have implications for policy makers' management of the use of nanomaterials in dentistry.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

AUTHOR CONTRIBUTIONS

Conceptualization: Marthinussen MC (equal), Cimpan MR (equal), Åstrøm AN (equal); **Investigation**: Xenaki V (equal), Åstrøm AN (equal); **Methodology**: Xenaki V (support), Marthinussen MC (support), Costea DE (support), Cimpan MR (support), Åstrøm AN (lead); **Formal analysis**: Xenaki

V (equal), Breivik K (equal), Lie SA (equal); **Writing – original draft**: Xenaki V (lead), Åstrøm AN (support); **Writing – review and editing**: Marthinussen MC (equal), Costea DE (equal), Breivik K (equal), Lie SA (equal), Cimpan MR (equal), Åstrøm AN (equal); **Supervision**: Marthinussen MC (support), Costea DE (support), Cimpan MR (support), Åstrøm AN (lead); **Funding acquisition**: Costea DE (equal), Cimpan MR (equal). All authors approved the final version of the manuscript for publication and agreed to be accountable for all the aspects of the work, ensuring that questions of accuracy or integrity of the work were appropriately investigated and resolved.

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