Radiation safety behavior model for dental hygiene departments of universities in South Korea

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ABSTRACT

Background: Dental hygiene departments in Korean institutions of higher education regularly use radiography systems for educating students. Despite reports indicating that exposure doses from these radiation-generating devices are small, and thus, present low risks for causing physical harm or chromosomal abnormalities, the large numbers of people who participate in oral examinations involving dental radiography raise questions about the optimal methods for managing radiation safety. ***Materials and Methods***: Social cognitive theory incorporating major variables pertaining to radiation safety management derived from the Haddon Matrix was used. This model proposes and refines an approach for enhancing the radiation safety behaviors of both professors and students in Korea's collegiate dental hygiene departments. ***Results:*** The results of the study indicate that professors respond most favorably to stated expectations for accomplishing effective radiation safety management; thus model proposes that enhancing safety behaviors among professors depends upon cultivating organizational environments with clear expectations. Students, in contrast, engage in desirable radiation safety management behaviors when they can display self-efficacy; thus, the model proposes that personal education that enhances their practical knowledge for engaging in desired behaviors is most desirable. ***Conclusion:*** To enhance the current radiation safety management behaviors of the collegiate dental hygiene departments in Korea, it will be helpful to establish a strategy arising from the model developed here.

Keywords: *Dental hygiene, Haddon Matrix, radiation safety, behavior, social cognitive theory.*

INTRODUCTION

In 2015, the dental hygiene departments of 83 colleges in Korea used radiography systems for student practice. The radiation-generating devices for diagnosis installed in dental hygiene departments included both intraoral and extraoral radiography systems, such as Panorama, Cephalo, and computed tomography (CT) scanning for dentistry. Some experts maintain that, because the exposure doses of intraoral radiation-generating devices installed in dental hygiene departments are relatively small, little possibility exists for these devices to cause physical or genetic abnormalities (1). The exposure dose of each inspection item is about 0.078 mSv in the case of a cone-beam CT scan, about 0.005 mSv in the case of intraoral radiography, about 0.019 mSv in the case of Panorama, and about 0.004 mSv in the case of Cephalo (2). The safety management of radiation exposure also is important because the number of people subject to oral examinations by the National Health Insurance Service is 18,269,720 annually (3) and the number of the cases of dental radiography (cone-beam CT, intraoral radiography, Panorama, and Cephalo) by the Ministry of Food and Drug Safety is 24,321,030 annually. In addition, sources in the implant dentistry field recently predicted that the number of cases of radiography will continue to increase because of increases in the use of cone-beam CT scans (4).

Regulatory authorities currently monitor educational institutions by checking the design safety of the radiation sources in use and by evaluating and inspecting the matters related to safety, ranging from the design stage of the facilities to the handling methods used during operations (5). Even when the same radiation-generating devices are in use, the provisions of the law are variously applied to medical institutions, veterinary hospitals, and educational institutions (6–8). Though system analyses of or guidelines for each institution's pursuit of radiation safety are diversely presented (9,10), the practical support for Korean colleges using radiation-generating devices and the budgets to fund radiation safety management are insufficient. As a result, the budgets of the educational institutions provide inadequate resources for taking appropriate actions to prevent radiation accidents. Moreover, because the procedures or safety management regulations for executing radiation safety management have failed to reflect sufficiently the realities of current circumstances, problems occasionally occur in each college (11). Accordingly, the study of Lim (2010) reports that required systematic education about radiation hazards, including the knowledge of exposure to radiation and the awareness of risk prevention, is unsatisfactory (12). In particular, in most private dental clinics in Korea, excluding large hospitals and some hospitals specializing in dentistry, the reality is that dental hygienists carry out most dental radiography work (13). In addition, the curriculum for teaching dental hygiene contains only two subjects that cover the content related to the use of radiation-generating devices and safety management (14–16). Most of the content is related to the methods of dento-maxillo-facial radiography (16). According to the Korean Dental Association, at least 4000 individuals whose major is dental hygiene graduate every year (17). The reality is that these graduates, in many cases, then carry out the work of radiography and safety management in dental clinics. Further, dental hygiene professors who have received radiation safety education for a short time, and not the professors who study radiation itself, carry out radiography skills education. As a result, in dental hygiene departments, the safety management of radiation-generating devices, which are not subject to sanctions pursuant to the Nuclear Safety Act, becomes an object of controversy. Therefore, examining the variables for enhancing radiation safety management throughout the learning process becomes important [5]. Health and medical service personnel should have accurate understandings of and alertness for preventing the exposure to radiation of patients and guardians of patients [18]. Students majoring in dental hygiene, who are preparing to become health and medical services personnel, should be educated systematically to improve their knowledge about, attitudes toward, and behaviors relative to radiation safety. Accordingly, in this study, we intend to develop a behavioral model of radiation safety management, in accordance with social cognitive theory and focused on the major variables related to radiation safety management derived from the Haddon Matrix. The goal of this model was to find an approach for enhancing radiation safety behaviors of professors and students in Korea's collegiate dental hygiene departments.

MATERIALS AND METHODS

This study's procedures included analyzing both the contents of preceding studies and the radiation safety management regulations of colleges, discovering the variables required for radiation safety management through field surveys, and developing a questionnaire after deriving radiation-safety management items by assigning weights to the major safety-related variables determined from three advisory meetings with experts. The experts for this study involved senior professors employed in the dental hygiene, radiology departments at specific universities in addition to radiation safety supervisors within institutions connected to the overall results of this study. Finally, the questionnaire was refined and supplemented by conducting two preliminary investigations and reviewing the results. The survey was carried out, over a 30-day period beginning April 23, 2015, among the professors and students of dental hygiene departments at 83 colleges across Korea.

The subjects of the analysis included 51 professors at dental hygiene departments, all of whom were female, and 723 students, including 708 females (97.9%) and 15 males (2.1%). In order to survey the most learned senior-year students, the subjects were selected from third-year students in departments with three-year curricula and fourth-year students in departments with four-year curricula. A total of 83 Korean Universities were evaluated in this study with a total of 83 professors surveyed and 51 responding, representing a percentage of 61.4%. Over 900 Korean University students were surveyed and 723 responded, representing a percentage of 80.3%.

The questionnaire included 10 questions related to the human factors that affect the management of radiation safety of professors and students (execution of health examinations before practice, wearing personal dosimeters, and so on), 5 questions related to factors pertaining to radiation-generating devices and radiation sources that employ hazardous materials (examination of grounding equipment, casing leakage and current and half-value layers, for instance), 4 questions for students and 8 questions for professors related to organizational environment factors (such as the periodic meetings of radiation safety committees), and 8 questions related to physical environment factors (calling attention to the prevention of radiation hazards and posting the expected maximum exposure doses, installation of alarm lamps at the entrances of rooms to indicate usage of radiation, furnishing radiation measuring instruments, and so on). These questions were selected as the safety management variables that related to prevention and used the four factors of the Haddon Matrix. In each case, levels of knowledge, attitude, and behavior were measured. Four questions related to self-efficacy and four questions related to the expectations that influence human behaviors were added.

The Cronbach's alpha values of the questionnaire for professors were as follows: behavior (hazardous material factor 0.868, human factor 0.821, organizational environment factor 0.921, and physical environment factor 0.838), attitude (hazardous materials factor 0.867, human factor 0.870, organizational environment factor 0.912, and physical environment factor 0.921), expectation for safety management (0.757), and self-efficacy (0.809). All of these values demonstrated reliability. For students, the Cronbach's alpha values were as follows: behavior (hazardous materials factor 0.920, human factor 0.892, organizational environment factor 0.889, and physical environment factor 0.886), attitude (hazardous materials factor 0.953, human factor 0.950, organizational environment factor 0.954, and physical environment factor 0.957), expectation for safety management (0.894), and self-efficacy (0.626). Again, these values all demonstrated reliability. The Haddon Matrix used in this study is a system presented in 1968. It intends to provide a persuasive framework that can identify diverse countermeasures to deal with injury problems by placing an emphasis on understanding the factors that cause the problems. It is utilized not only in emergency response domains, such as in the public health and medical sectors and in emergency medical support, but also, recently, in diverse applications like preventing workplace violence [19–21]. In this study, the Haddon Matrix was applied to design systematically a plan to find the causes of problems associated with radiation safety management behaviors and to cope with them. In addition, not only the theories related to safety, such as the Haddon Matrix, but also cognitive-behavioral approaches are essential for understanding human behaviors, including radiation safety management in social conditions. The social cognitive theory emphasizes that the behavior and cognition of an individual affect his or her future behaviors, and, further, that behaviors, personal factors, and environmental factors interact with one another as the medium of learning [22]. Accordingly, in this study, we applied the social cognitive theory that emphasizes reciprocal determinism as the major component for understanding human behaviors.

Statistical analysis were carried out using standard softwares (SPSS 15.0, AMOS 7.0) to calculate the average, standard deviation, Pearson correlation coefficient, multiple regression, and path analysis. To evaluate whether the model was suitable for the data or not, goodness of fit verification was carried out using the χ^2 statistic, χ^2 statistic/degree of freedom (df), degree of freedom, GFI (Goodness-of-Fit Index), AGFI (Adjusted Goodness-of-Fit Index), RMSEA (Root Mean Square Error of Approximation), CFI (Comparative Fit Index), and TLI (Tuker Lewis Index).

RESULTS

Radiation safety management based on the Haddon matrix

The radiation safety management behaviors of professors showed diverse levels ranging from a minimum of 2.90 ± 1.45 points (out of 5 points) to a maximum of 4.59 ± 0.61 points. The radiation safety management behavior levels of students were relatively low, showing values from a minimum of 2.37 ± 1.21 points to a maximum of 3.81 ± 1.12 points. In the case of professors, periodic attendance at meetings of radiation safety committees (2.94 ± 1.36 points), which is a social environment factor, and opening and closing interlocking devices in the radiography system use facility (2.90 ± 1.45), which is a physical environment factor, showed low levels. In the case of students, periodic measurement of radiation dosage (2.89 ± 1.29 points), execution of health examinations before the first practice (2.48 ± 1.22 points), and wearing of personal dosimeters (2.37 ± 1.21 points), which are human factors, showed low levels. Also, exposure, examination results, and expected exposure checking systems (2.88 ± 1.20 points), which together are a social environment factor, and furnishing a radiation measuring instrument in the practicing room (2.98 ± 1.27 points), which is a physical environment factor, showed low levels (table 1).

Correlations between factors affecting radiation safety management

As a result of reviewing, for professors, the correlation between the major variables that account for radiation safety management in the Haddon Matrix, many variables showed no correlation. The attitude toward hazardous materials and the attitude toward the physical environment showed the highest correlations at 0.768. In other words, the physical environment can be considered well established only if safety measures protecting against hazardous materials are well secured. In the case of students, all the variables were shown to correlate with one another, as in social cognitive theory, with the exception of the correlation between the self-efficacy variable and knowledge about the physical environment. Among them, the attitude toward the physical environment and the attitude toward the human factor were shown to have the highest correlation (0.896). That is to say, the stronger is the thought that the physical environment should be well established, the stronger is the thought that human behaviors actually can be carried out (table 2).

Variables affecting radiation safety management behaviors

Carrying out a multiple linear regression analysis, using as a dependent variable the radiation safety management behaviors of professors at dental hygiene departments, yields the finding that attitudes toward the organizational environment and expectations for the results of radiation safety management both affected radiation safety management behaviors. That is to say, a well-established organizational environment enhances the levels of radiation safety management behavior. Further, because radiation safety behaviors can be enhanced only when the expectation for radiation management is high, a strategy to enhance the organizational environment is required. The explanatory power

Table 1. Radiation safety management levels of dental hygiene departments based on the Haddon matrix.

Human factors	Professor	Student
Periodic measurement of radiation dose	1.14 ± 3.94	1.29 ± 2.89
Health examination before first practice	1.33 ± 3.84	1.22 ± 2.48
Wearing of personal dosimeter	1.42 ± 3.94	1.21 ± 2.37
Execution of radiation shielding	1.01 ± 4.47	1.31 ± 3.34
Reduction in exposure time	0.61 ± 4.59	1.09 ± 3.74
Maintenance of a distance from the radiation source	0.83 ± 4.43	1.11 ± 3.59
Defensive education	0.88 ± 4.45	1.12 ± 3.81
Radiography practice over a human body	1.24 ± 3.98	1.32 ± 3.21
Familiarization of precautions against prevention of radiation hazard	1.11 ± 4.25	1.11 ± 3.53
Familiarization of emergency evacuation route (method)	1.09 ± 3.92	1.19 ± 3.12
Hazardous materials factors	Professor	Student
Indexes for management of radiation generating devices (checklist)	0.11 ± 4.00	1.31 ± 3.24
Accuracy management for exposure dose (tube voltage, tube current, and exposure time)	1.20 ± 3.63	1.22 ± 3.23
Performance of the radiation field adjustment device	1.17 ± 3.69	1.20 ± 3.07
Storage and use of radiation generating devices in a radiation controlled area	0.52 ± 4.67	1.21 ± 3.77
Checking of grounding equipment, casing leakage current and half value layer	1.24 ± 3.45	1.24 ± 3.04
Organizational environment	Professor	Student
Communication about safety among students, professors and radiation safety managers	1.07 ± 3.82	1.13 ± 3.46
Exposure, examination result, and expected exposure dose checking system	1.15 ± 3.20	1.20 ± 2.88
Influence of the radiation safety manager	1.22 ± 3.53	1.22 ± 3.18
Time allocation to education (familiarization) of radiation safety management regulation	1.30 ± 3.27	1.13 ± 3.33
Management's awareness of the importance of radiation safety management	1.23 ± 3.56	–
Registration of professors and lecturers as radiation workers	1.25 ± 4.04	–
Periodic opening of radiation safety committee	1.36 ± 2.94	–
Conveyance of radiation safety management from the regulatory agencies	1.33 ± 3.49	–
Physical environment	Professor	Student
Locking device of practicing room	1.06 ± 4.14	1.16 ± 3.74
Marking of entrance use	1.33 ± 3.96	1.26 ± 3.63
Opening/closing interlocking device for the entrance of the facility used	1.45 ± 2.90	1.26 ± 3.10
Attention to prevention of radiation hazard/posting of the expected maximum exposure dose	1.39 ± 3.04	1.22 ± 3.06
Furnishing of shielding apparatuses (lead apron, lead gorget, and lead glasses)	0.82 ± 4.35	1.12 ± 3.80
Announcement of the contact information of the radiation safety manager	1.04 ± 4.25	1.28 ± 3.29
Furnishing of radiation measuring instrument	1.46 ± 3.30	1.27 ± 2.98
Furnishing of human body phantom	1.20 ± 4.18	1.33 ± 3.46

The values of the items by factor are shown by average and standard deviation (m ± SD) with a maximum of 5 points. The scores for knowledge, attitude, and behavior have a minimum of 1 point and maximum of 5 points. The scores for expectation and self-efficacy range between a minimum of 1 point and a maximum of 7 points.

The knowledge level of the professors in dental hygiene departments is 4.65 ± 0.39 points: human factor, 4.58 points; hazardous materials factor, 4.69 points; organizational environment factor, 4.40; and physical environment factor, 4.71 points. The attitude level is 4.52 ± 0.47 points: human factor, 4.58 points; hazardous materials factor, 4.56 points; organizational environment factor, 4.43 points; and physical environment factor, 4.53 points. The behavior level is 3.82 ± 0.72 points: human factor, 4.18 points; radiation source factor, 3.89 points; organizational environment factor, 3.47 points; and physical environment factor, 3.76 points. The level of expectation for radiation safety management is 5.76 ± 0.86 points; the level of self-efficacy is 5.03 ± 1.06 points.

The knowledge level of the students in dental hygiene departments is 4.13 ± 1.15 points: human factor, 4.01 points; hazardous material factor, 4.03 points; organizational environment factor, 4.48 points; and physical environment factor, 4.17 points. The attitude level is 4.25 ± 0.63 points: human factor, 4.24 points; hazardous materials factor, 4.21 points; organizational environment factor, 4.25 points; and physical environment factor, 4.27 points. The behavior level is 3.28 ± 0.84 points: human factor, 3.21 points; hazardous materials factor, 3.27 points; organizational environment factor, 3.21 points; and physical environment factor, 3.38 points. The level of expectation for radiation safety management is 5.03 ± 1.15 points; the level of self-efficacy is 4.29 ± 0.94 points.

was 52.9%. As a result of carrying out a similar multiple linear regression analysis, using as a dependent variable the radiation safety management behaviors of students at dental hygiene departments, self-efficacy, and knowledge about hazardous materials were shown to affect radiation safety management behaviors. In contrast to professors, students needed education that enhanced their knowledge of radiation-generating devices to improve their radiation safety behaviors. In addition, as the theory of Bandura predicted, the strategy of enhancing self-efficacy required additional preemptive application more than it depended upon improvement of knowledge (table 3).

Table 2. Correlations between the human factors, hazardous materials, and environmental variables affecting radiation safety management.

Professor	BM	BH	BS	BP	KM	KH	KS	KP	EM	EH	ES	EP	EX	SE
BM	1													
BH	.627**	1												
BS	.580**	.705**	1											
BP	.573**	.572**	.765**	1										
KM	.218	.312*	.068	.137	1									
KH	.006	.286*	.248	.160	.441**	1								
KS	.031	.239	.331*	.275	.000	.309*	1							
KP	.234	.263	.305*	.326*	.173	.558**	.435**	1						
EM	.532**	.445**	.265	.276	.223	.012	.193	.328*	1					
EH	.365**	.591**	.447**	.311*	.152	.237	.292*	.301*	.744**	1				
ES	.477**	.519**	.481**	.530**	.149	-.037	.339*	.231	.630**	.681**	1			
EP	.403**	.426**	.273	.301*	.231	.117	.154	.256	.768**	.725**	.701**	1		
EX	.546**	.460**	.465**	.437**	.179	.058	.121	.206	.586**	.492**	.445**	.460**	1	
SE	.300*	.587**	.344*	.283*	.246	.257	.030	.241	.391**	.502**	.218	.356*	.576**	1
Student	BM	BH	BS	BP	KM	KH	KS	KP	EM	EH	ES	EP	EX	SE
BM	1													
BH	.717**	1												
BS	.668**	.773**	1											
BP	.682**	.783**	.760**	1										
KM	.295**	.260**	.186**	.235**	1									
KH	.163**	.228**	.132**	.179**	.644**	1								
KS	.162**	.209**	.167**	.190**	.528**	.688**	1							
KP	.175**	.200**	.108**	.217**	.514**	.730**	.763**	1						
EM	.263**	.266**	.197**	.242**	.372**	.444**	.371**	.401**	1					
EH	.207**	.274**	.189**	.279**	.350**	.481**	.388**	.427**	.848**	1				
ES	.223**	.258**	.203**	.273**	.347**	.438**	.414**	.423**	.815**	.894**	1			
EP	.222**	.249**	.189**	.288**	.349**	.447**	.385**	.463**	.822**	.896**	.883**	1		
EX	.272**	.287**	.277**	.286**	.231**	.165**	.139**	.123**	.354**	.323**	.328**	.314**	1	
SE	.346**	.428**	.433**	.413**	.164**	.133**	.092*	.072	.144**	.143**	.119**	.117**	.478**	1

BM (behavior of material factors), BH (behavior of human factors), BS (behavior of social environmental factors), BP (behavior of physical environmental factors), KM (knowledge of material factors), KH (knowledge of human factors), KS (knowledge of social environmental factors), KP (knowledge of physical environmental factors), EM (attitude of material factors), EH (attitude of human factors), ES (attitude of social environmental factors), EP (attitude of physical environmental factors), EX (Expectation for behavior), and SE (Self-Efficacy).

Knowledge, attitude, and behavior are major variables in traditional education models. Hazardous materials (radiation-generating devices), human factors, social environment, and physical environment are major variables in the Haddon Matrix.

Table 3. Variables affecting radiation safety management behaviors of personnel in dental hygiene departments

Independent variable	Professor					Student				
	Independent variable Non-standardized coefficient		Standardized coefficient	t	Significance probability	Non-standardized coefficient		Standardized coefficient	t	Significance probability
	Independent variable B	Standard deviation	Beta			tSignificance probability B	Standard deviation	Beta		
tSignificance probability (Constant)										
-1.112 1.229 -.905 .371 .268 .217 1.234 .218 Knowledge about hazardous materials (KM)	-.004	.156	-.003	-.024	.981	.073	.022	.144	3.343	.001
Knowledge about human behaviors (KH)	.095	.119	.156	.797	.431	-.034	.019	-.101	-1.824	.069
Knowledge about organizational environment (KS)	.018	.144	.018	.128	.899	.044	.044	.053	.986	.325
Knowledge about physical environment (KP)	.064	.134	.077	.475	.638	.025	.025	.057	1.003	.316
Attitude toward hazardous materials(EM)	-.046	.362	-.031	-.127	.900	.083	.080	.067	1.036	.301
Attitude toward human behaviors (EH)	.058	.388	.037	.149	.882	.022	.118	.017	.188	.851
Attitude toward organizational environment (ES)	.639	.249	.551	2.571	.014	.066	.097	.055	.688	.492
Attitude toward physical environment (EP)	-.297	.277	-.232	-1.072	.290	.069	.106	.054	.652	.514
Expectation for radiation safety management (EX)	.223	.133	.270	1.682	.101	.026	.029	.035	.903	.367
Self-efficacy (SE)	.129	.106	.191	1.217	.231	.353	.033	.396	10.733	.000
	F = 4.266(0.001) R^2 = 0.529					F = 27.811(0.000) R^2 = 0.287				

As shown in table 3 the explanatory power for this experiment was R2 52.9% which relates to the multi-variate equivalent of the bivariate correlation coefficient. The F- value signifies that the model did a good job in predicting that there is a significant relationship between the set of variables outlined in this study and the dependent variables.

Behavioral model of radiation safety management

The goodness of fit of a structural equation model was evaluated using adjusted goodness of fit (AGFI), root mean square error of approximation (RMSEA), root mean square residual (RMSR), or the normed fit index (NFI) in general. If the RMR or RMSEA was between 0.05 and 0.08, the model was regarded as a fit one. If the goodness-of-fit index (GFI) was 0.9 or higher, the model was judged to be a good one. If the AGFI was 0.9 or higher, the model was judged to be a good one. It is, by nature, similar to the R-squared (R^2) of regression analysis. NFI is an index that shows what percentage of reduction is the gap between the analysis model and the independent model; it has a value between 0 and 1. If the value is 0.9 or higher, it is judged, in general, to be a fit model.

As a result of verifying the goodness of fit of the radiation safety management model of the professors at dental hygiene departments, RMR was judged to be a fit model, and RMSEA, GFI, NFI, and AGFI were found to have low goodness of fit. There was no significant change in the values even when the model was modified. When we looked into the goodness of fit of the radiation safety management model of the students, RMR, RMSEA, GFI, and NFI were found to be fit models, and AGFI was also found to be an almost fit model. In a confirmatory factor analysis, when the standardized estimate β of a potential factor was 0.5 or higher, the relevant factor was analyzed to be very significant in general. As a result of carrying out a path analysis for both the professors and students, all of the items of knowledge were found to be significant, including knowledge about hazardous materials, human factors, the organizational environment, and the physical environment. The attitudes toward all items were found to be significant, including attitudes toward hazardous materials, human factors, the organizational environment, and the physical environment. Behaviors were also found to be significant in all behavioral items, including those involving hazardous materials, human factors, the organizational environment, and the physical environment as shown in table 4.

When we looked into the path coefficient of the radiation safety management behavior model of the professors in detail, knowledge was found to have no effect on attitude. The only variable that had an effect on behavior was expectation ($\beta = 0.330$, $p < 0.05$). Self-efficacy, attitude, and knowledge were found to have no effect ($p<0.05$). The higher the expectation for radiation safety management was, the greater the effect on the behavior was shown to be. Expectation and self-efficacy were shown to correlate positively, which was statistically significant ($p < 0.01$). Two pairs of factors, knowledge and self-efficacy and knowledge and expectation, did not show any statistical significant correlation ($p < 0.05$). Because such variables as knowledge, attitude, and self-efficacy have no great significance among professors, enhancing the radiation safety management behavior level of the professors in dental hygiene departments requires an intervention strategy to enhance the level of expectations for the results of radiation safety management as shown in table 5 and figure 1.

When we looked in detail at the path coefficient of the radiation safety management behavior model of the students, knowledge was found to have a statistically significant effect on attitude ($\beta = 0.529$, $p<0.01$). Among the variables that had an effect on behaviors, the expectation for radiation safety management did not have a statistically significant effect ($p<0.05$). Self-efficacy ($\beta = 0.418$, $p<0.01$) and attitude had a significant effect ($\beta = 0.173$, $p<0.01$). The variables that had greater effects on behavior were found to be self-efficacy, attitude, and knowledge, in that order. The higher the level of self-efficacy, attitude, or knowledge, the bigger the effect on behavior was found to be. In addition, the pairs, expectation and self-efficacy, knowledge and expectation, and knowledge and self-efficacy, were all found to have positive correlations that were statistically significant ($p<0.01$) as shown in table 5 and figure 2.

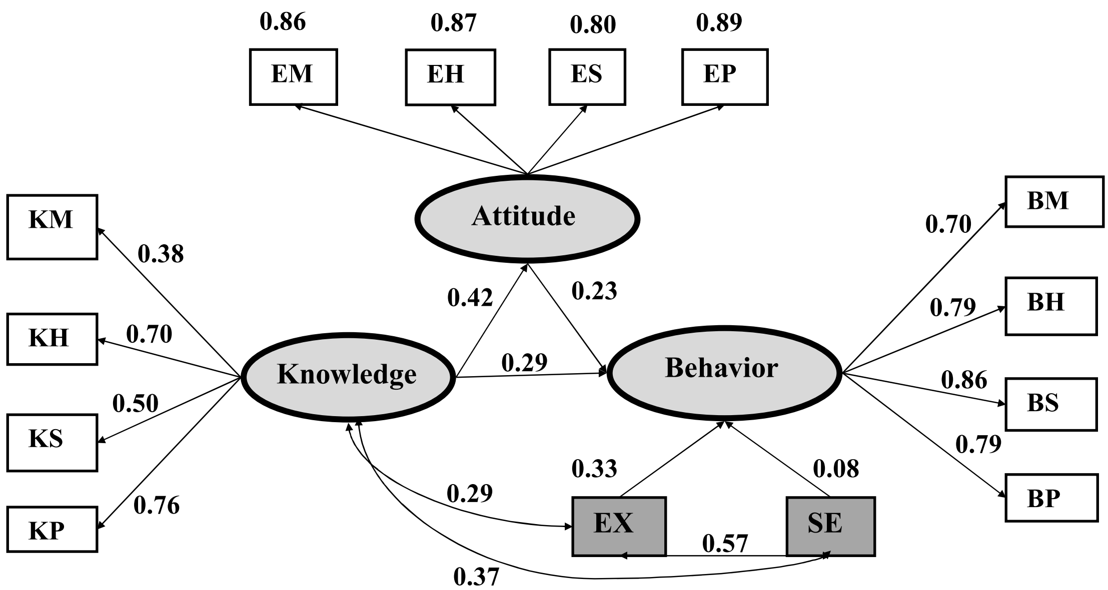

Figure 1. Professors' behavioral model of radiation safety management through structural function. BM (behavior of material factors), BH (behavior of human factors), BS (behavior of social environmental factors), BP (behavior of physical environmental factors), KM (knowledge of material factors), KH (knowledge of human factors), KS (knowledge of social environmental factors), KP (knowledge of physical environmental factors), EM (attitude of material factors), EH (attitude of human factors), ES (attitude of social environmental factors), EP (attitude of physical environmental factors), EX (Expectation for behavior), and SE (Self-Efficacy).Knowledge, attitude, and behavior are major variables in traditional education models. Hazardous materials (radiation-generating devices), human factors, social environment, and physical environment are major variables in the Haddon Matrix.

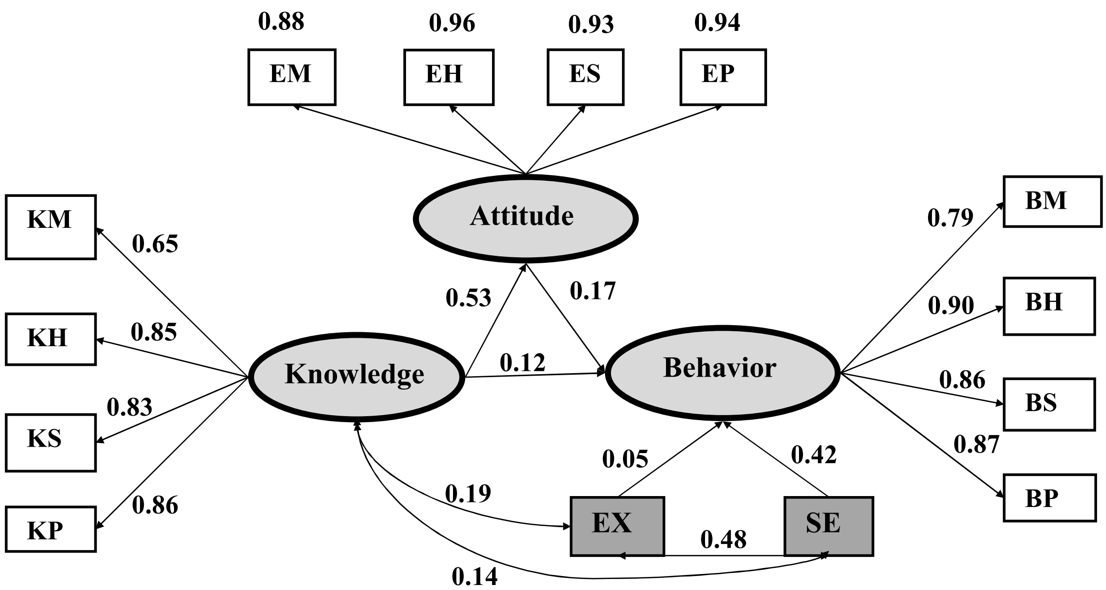

Figure 2. Students' behavioral model of radiation safety management through structural function. BM (behavior of material factors), BH (behavior of human factors), BS (behavior of social environmental factors), BP (behavior of physical environmental factors), KM (knowledge of material factors), KH (knowledge of human factors), KS (knowledge of social environmental factors), KP (knowledge of physical environmental factors), EM (attitude of material factors), EH (attitude of human factors), ES (attitude of social environmental factors), EP (attitude of physical environmental factors), EX (Expectation for behavior), and SE (Self-Efficacy). Knowledge, attitude, and behavior are major variables in traditional education models. Hazardous materials (radiation-generating devices), human factors, social environment, and physical environment are major variables in the Haddon Matrix.

Table 4. Verification of the goodness of fit of radiation safety management behavioral models for dental hygiene departments

Classification	RMR	RMSEA	GFI	AGFI	NFI	χ^2	df	p
Professor	.078	.161	.689	.541	.668	158.861	71	.000
Student	.076	.080	.925	.890	.950	392.572	71	.000

The goodness of fit for the model and sample data were verified using the chi-square ($\chi2$) statistic ($p > 0.05$ is desirable). Because the $\chi2$ statistic is sensitive to the sample size, if the sample size is about 200 or bigger, the result is presented as if there were a difference, even though there is no statistically significant difference. In addition, if the sample size is 100 or smaller, the result is presented as if there were no difference, even though there is a statistically significant difference. Accordingly, (A)GFI, RMSEA, RMSR, and NFI are most widely used for performing goodness-of-fit evaluations of structural function models.

Table 5. Path analysis of radiation safety management behavior

Regression Weights			Professor				Student			
			β	B	S.E.	C.R.	β	B	S.E.	C.R.
Attitude	⇐	Knowledge	0.418	0.712	0.403	1.764	0.529	0.286	0.024	12.043**
Behavior	⇐	Expectation	0.330	0.233	0.112	2.083*	0.052	0.038	0.028	1.348
Behavior	⇐	Self-efficacy	0.083	0.048	0.09	0.529	0.418	0.373	0.036	10.384**
Behavior	⇐	Attitude	0.231	0.337	0.222	1.519	0.173	0.246	0.06	4.106**
Behavior	⇐	Knowledge	0.294	0.729	0.54	1.351	0.117	0.09	0.034	2.636**
Expectation	⇔	Self-efficacy	0.569	0.518	0.151	3.425**	0.476	0.513	0.045	11.377**
Knowledge	⇔	Self-efficacy	0.367	0.095	0.059	1.605	0.135	0.139	0.042	3.329**
Knowledge	⇔	Expectation	0.292	0.062	0.044	1.405	0.191	0.238	0.052	4.605**

DISCUSSION

Korean radiation safety regulations include safety regulation activities for radiation sources, radioactive waste, and radiation workers. The safety control for radiation workers includes, for example, radiation exposure dose control, management of people with readings that exceed the dose limit or are not valid, and reading work regulations. Through these measures, the safety and health management for radiation workers, examination of the radiation level and safety in radiation controlled areas, and professionalism of reading work are reinforced [5]. Because the behavior level of personnel in dental hygiene departments regarding radiation safety management is shown to be low in different domains, such as human factors, social environment factors, and physical environment factors, it is necessary to increase desirable behaviors in all of the variable domains of the Haddon Matrix. Though requirements mandate regular management of X-ray devices and designate appropriate radiation hazard prevention apparatuses as parts of the safety management of X-ray devices used for diagnosis, exposure times should be reduced, or distances should be maintained in order to minimize exposure to X-ray radiation. Considering the level of safety management found as a result of this study, it is thought that sufficient safety will be secured only when the safety level is improved [23–27]. Some experts opine that we do not need to worry about the dangers of radiation-generating devices used in colleges and that we ought to take reasonable actions to reduce exposure as far as possible. If a standard, such as an ignorable risk level or a socially allowable risk level exists, we can say that reducing the risk to that level can be viewed as a method of risk management. For example, a legal principle for risk management exists under the law in the United Kingdom; there such a critical attitude is demonstrated by the principle of “as low as reasonably practicable” (ALARP) [28]. Because the International Commission on Radiological Protection also follows ALARP as a main principle, it has been applied as well to the

Nuclear Safety Act of Korea (29–31). This study employed the Haddon Matrix and social cognitive theory to develop a behavioral model of radiation safety management that can be approached strategically by examining the safety levels of the professors and students using radiological devices in collegiate dental hygiene departments and then used to enhance radiation safety. Behavioral scientists have found creative uses for social cognitive theory to advance the education, processes, and technologies that, based on cognitive variables, serve to enhance the possibilities for behavioral changes (32–34). As the social cognitive theory on motives for actions rapidly emerged in the 1980s, many studies on self-efficacy and expectation were carried out. As a result, learners began to be regarded as active agents rather than passive beings (35–36). The result of this study also showed the importance of variables, such as self-efficacy in the case of students, and expectation, in the case of professors, for enhancing radiation safety management behaviors. That is to say, to enhance radiation safety behaviors, a strategy to increase the level of expectations for the results of behaviors, rather than a strategy to increase knowledge, should be applied in the case of professors. In the case of students, the application of a personality program that preemptively increases self-efficacy, rather than a program focused on increasing the knowledge related to their specialties, is required. Self-efficacy is one's judgment of the personal ability to organize and carry out the actions required to accomplish a certain result. Accordingly, the level of confidence in one's ability is the judgment of the efficacy that the action, which requires that ability, can be well carried out and expressed as an action [37]. Education to enhance self-efficacy and accumulation of knowledge about radiation-generating devices need to be pursued together. Attitude means both the level of positive or negative evaluation made by an individual when performing a specific behavior (38) and the belief that indicates the attitude toward doing a certain behavior. Attitude is a variable long recognized in social psychology as a predictor of behaviors (39). In the case of students, because attitude is a variable more effective at enhancing safety behaviors than at increasing the knowledge related to their specialties, it is necessary to take students' attitudes into account when designing an education system. As a result of applying this approach in this study, we, as well, found a useful pattern. Though the level of the professors' knowledge about radiation safety management was high, the level of behavior was low in comparison to their levels of knowledge and attitude. In addition, from the fact that only the expectations for radiation safety management act on the radiation safety management behaviors of professors, we predicted that enhancing safety behaviors would be difficult without the professors choosing personally to cooperate. In such cases, an organizational environment that can enhance the level of expectation for the desired result should be devised. In the case of students, because self-efficacy had the greatest effect on radiation safety management behaviors, personality education that enhances self-efficacy more than it emphasizes knowledge is a necessary application. Dental hygiene specialists in charge of radiography work in a dental clinics should properly practice college education first to enhance radiation safety management behaviors. On this basis, health and medical service personnel who practice radiation safety management at work can be encouraged (40). To enhance the current radiation safety management behaviors of the collegiate dental hygiene departments in Korea, it will be helpful to establish a strategy arising from the model developed here. Additional models, based on this study's results, can be developed to enhance safety practices.

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