Development and evaluation of a nutrition management support system using ontology

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Objective: To report the development and evaluation of a nutrition management support system using ontology-based terminology extraction from four selected guidelines concerning nutrition management.

Method: The system was applied to the diet of 2 clients for 2 months and evaluated by 3 nationally registered dietitians, in the present study referred to as, “test professionals”: 2 novices, with 3 and 4 years of experience; and 1 expert, with 19 years of experience. The system was evaluated on two aspects: filling-out times for the response forms by the test professionals, and the Canberra distance, calculated through a hierarchical cluster analysis of the filled-out data.

Results: A radar chart was successfully developed showing problem points, guidance-related suggestions and comments, and food-group deviations. All test professionals reduced their respective form filling-out times over the course of this system’s implementation—the novices by approximately 26% and the expert by approximately 32%. Further, hierarchical cluster analysis revealed that the system was shorten the Canberra distance between the novices and the expert by 12.9 for the “Food Exchange Lists” and by 8.6 for the “Calorie Intake Amounts.”

Conclusion: The system developed and tested described in the present study could reduce the time required for dietitians to provide nutritional guidance and could be used as a “bottom-up” approach to improve the nutritional-guidance-related abilities of new nationally registered dietitians.

Key words: nutrition management support system, ontology, nationally registered dietitian

Introduction

As Japan enters the era of the “ultra-aging society,” better control of everyday nutrition and eating styles is a means of preventing diabetes and frailty-related care.1 The effects of such control also contribute to the extension of healthy-life expectancy. However, people make their own choices with regard to food, and eating-related care of clients with diabetes is performed individually, with a need for long-term supervision.1 Thus, a system that can perform a wide range of functions is needed: enabling an individual to incorporate her own eating needs in her self-care and allowing a nationally registered dietitian to have a firm grasp of the eating patterns of each client in order to provide relevant nutritional and eating-related information based on practical evidence. This system would thus enable more efficient nutrition management for each user.

The nutrition management system used widely in Japan at present is based on the American Dietetic Association (ADA) system called the Nutrition Care Process (NCP).2 This process assists national registered dietitians in helping clients better meet their health and nutrition goals, and has four steps: 1. Nutrition Assessment, 2. Nutrition Diagnosis, 3. Nutrition Intervention, and 4. Nutrition Monitoring and Evaluation. The goal has been to standardize and integrate these processes to provide high-quality nutritional care and achieve optimal results. The ADA hoped that the NCP would become standardized for international use, convened representative nutritionists from each country, and held a meeting in Chicago in 2005. Nakamura who participated as a representative of Japan in this meeting described that is meaningful for national registered
dietitian to acquire and utilize NCP criteria for determining nutritional status, education, etc. In Japan, Nutrition Care and Management (NCM), has been established as the most common system. It has seven components: Nutrition Screening, Nutrition Assessment, Nutrition Care Plan, Performance and Checking, Monitoring, Evaluation and Quality Control or the "Finished nutrition management," and Continuous Quality Improvement. NCM serves as an index for use in nutrition management systems within the Japanese health insurance and long-term care insurance system. Because there are no set key terms for NCM, nationally registered dietitians employ terminology used in guidelines for each respective disease; however, each guideline uses slightly different terminology; therefore, there is no uniformity. Meanwhile, the existing nutrition management computer system has been developed as main functions for food-services provision. Other than it, functions based on the NCM components, is to evaluate inputted client food records and then display diagnostic results on screen. Further, numerous terms used by administrative dietician for daily work are stored in computer, but it is difficult to reuse it efficiently.

An ontology can clarify vocabulary (terms) definitions by their class, e.g., high or low rank, and their relationships. The objectives of the present study are to: 1. perform an ontology-based extraction of terminology from the guidelines for each type of disease and for healthy persons’ nutrition (e.g., the "Diabetes Guide," "Food Exchange Lists," "Japanese Food Guide," and "Dietary Guidelines"); 2. develop a nutrition management support system for nationally registered dietitians using the extracted terms, in two parts: a client records support (CRS) system, which can be easily used by nationally registered dietitians and their clients, and a nutritional guidance support (NGS) system; and 3. have 3 test professionals evaluate the overall usefulness of the system.

Materials and Methods

Materials

The first set of guidelines used was the Treatment Guide for Diabetes 2016—2017, the "Diabetes Guide."6 The second was the "Food Exchange Lists, 7th Edition: Dietary Guidance for Persons with Diabetes."7 The third was the Japanese Food Guide Spinning Top, called the "Japanese Food Guide."8,9 The fourth was the "Dietary Guidelines."10 The words in each of these guidelines were the first tagged manually for part-of-speech (noun, verb, adjective). The other 6 parts of speech were not used as the terms. The Hozo ontology editor was used to group terms by class, attribute, and relation.10

Extracted terminology was compounded in a database using phpMyAdmin version 4.4.12. This software can run MySQL, which is a database system, and manage it by server online. The server computer was a Dell Inspiron 660s with Intel Core i5-3450s processor, 2.80 GHz CPU, 6 GB DDR3 SDRAM, and a 64-bit operating system.

Databases

A total of 6 databases were developed: 5 relational databases and 1 hierarchical database. Relational databases were "Client's eating record," "Record of client's weight and blood sugar level," "Standard client data," "Standard reference values," and "Information on meals and food items." The hierarchical database was "Nutritional guidance concepts."

System development

Our nutrition management support system is comprised of a CRS system and an NGS system. The two elements of the overall system were constructed application software using PHP version 5.6.6 and HTML. In the CRS system, we developed the following three functions. 1. To enable inputs by clients to record their daily eating practices such that the nationally registered dietitian can also view these client records. 2. To organize meal data according to the food groups in the "Food Exchange Lists." 3. When the client selects meal and food information in the relevant database, to display intake amounts and nutritional values.

In the NGS system, a nationally registered dietitian provides nutrition guidance to a client while evaluating their dietary excesses and/or insufficiencies. The NGS, based on the hierarchical database "Nutritional Guidance Concepts" and drawing on the other 5 databases, helps dietitians collect the necessary information.

Three nationally registered dietitians with 3, 4, and 19 years of professional experience respectively were asked to test this system. These test professionals were divided into two groups: 2 novices in one group and 1 expert in the other. The client assessment data presented to the test professionals were simulated record values for 2 healthy clients, covering self-monitoring of blood glucose (SMBG), body weight, and food records for 2 months. They were input into the CRS system by one of the authors, who is a licensed nationally registered dietitian. In addition, the food and meals not described in the guidelines that clients ate were input and registered as new data into the system. Therefore, understanding
the client's information communication technology skills was not a consideration in this study. Client assessment data was displayed on the NGS system screen, along with another screen displaying only the average monthly value of the assessment item and the patient's reference value.

The system was tested with a Fujitsu Arrows Tab running Windows 8.1, 1.46 GHz quad core CPU, 4.00 GB RAM, and a 32-bit operating system. We created response forms for test professionals to record nutritional assessment and guidance details for each client using the terminology extracted from the guidelines and the recommended values. Response forms included detailed selection choices on SMBG values, calorie intake amounts, body mass index (BMI), and other items within the "Standard Reference Values" database. In the database, nutritional guidance on consumption units is summarized as the "Exchange Lists for Diabetes" and serving sizes of staple foods, side dishes, and main dishes are summarized as "Meal Dish Combinations."

Response forms were filled out by hand to avoid discrepancies due to differences in typing speed. The handwriting speed was ignored. To ensure that the test professionals had the same level of familiarity with the interface, we recorded their input after they had used it for 3 months. We recorded total filling-out times and compared those among the test professionals depending on whether they were using the system or not to help consider factors influencing those filling-out times among nationally registered dietitians.

The nouns, verbs, and adjectives that test professionals recorded on their response forms when using the system and not using it were divided by morphological analysis and the frequency of each. Cluster analysis grouped test professionals by similar part-of-speech composition and showed its dissimilarity in distance as a scale, with the frequency of use of each word class presented across the groups. In this evaluation, a longer distance equates to more dissimilarity, whereas a shorter distance indicates less dissimilarity. In this study, Canberra distance was measured by the group average method in R version 3.3.1.11

**Results**

**System development**

Figure 1 shows an overview of the overall system, which is comprised of the CRS system and the NGS system. From the four guidelines, 252 terms were extracted and assigned to 6 databases. To link these two systems, as shown in Figure 2, 59 terms were selected to apply as field names for the respective databases: 7 terms were used for the "Food Records of Clients" database, 4 for the "Record of Client Body Weight and SMBG" database, 4 for the "Standard Client Data" database, 23 for the "Standard Reference Values" database, 16 for the "Meals and Food Items Information" database, and 5 for the "Nutritional Guidance Concepts" database.

The CRS system can be used to display lists of food items from the "Meals and Food Items Information" database. Using a drop-down menu, selections of meals and food items that the client has actually eaten can be made. Daily records kept by the client with the CRS system can be incorporated within the "Food Records of Clients" and "Record of Client Body Weight and Glucose Levels" databases. Both clients and their national registered dietitians could view changes over time in the client's calorie intake amounts, BMI, SMBG, etc. and compare them with numerical values in the "Standard Reference Values" database. Further, information from the Food Exchange Lists, with foods/meal's and nutritional information plus the client's own information on calorie intake amounts, body weight, SMBG, among others, could be seen at a glance as the result averaged over a 1-month period calculated by the CRC system.

The NGS system, shown in Figure 3, is divided into 4 sections: (A−D). In Figure 3 (A1), "today's values" can be seen as well as "1-month previous values." The value entered for any day selected can also be viewed, using the CRS system. Furthermore, when today's value and/or the 1-month previous value deviate from a standard reference value, cells with those values will automatically be displayed with a red background.

In Figure 3 (A2), the cells display the results of a comparison between today's values and the 1-month previous values; for lower, identical, and higher values, a "↑" sign, a "→" sign, or a "↓" sign is displayed, respectively. Additionally, when today's values are higher than the standard reference values, the cells are displayed with a red background, and if the values are lower, then the background is blue. This enables system users to see at a glance whether their values are "higher" or "lower" than they should be.

Figure 3 (B) displays food consumed by the client over the past month, based on the Food Exchange Lists, 1−6. Food group assignments were made automatically by this system based on the "Meals and Food Items Information" database.

In Figure 3 (C), assessment results are displayed using a radar chart: BMI, carbohydrate percentage of total calories or "carbohydrate ratio," and the "6 list & Seasonings of The Food Exchange." This enabled users
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Figure 1. System development flow

Figure 2. Respective database applied as field names of 59 terms
Figure 3. Nutrition Guidance Support System: sample screens

(A1) Values recorded by the client: today's and 1 month's previous values. (A2) Examples can be assessed visually on guidance for the next month. (B) Dish and foods recorded by client. (C) Radar chart showing today's and the previous month's values equivalent to standard reference values "1" (values shown as percentages). (D) Comment display: examples of nutritional guidance-related comments (scrolling is enabled at the right), with space for text input (at the left).

Figure 4. Response Form recording times by the test professionals
Appendix 1. Response forms

Figure 5. Hierarchical cluster analysis results

Numbers show the Canberra distance.
to easily find items that showed excesses and/or insufficiencies.

As shown in Figure 3 (D), a text-input screen is provided on the left side of the comment display portion. Here, the system displays points of concern for the client and suggests changes based on the "Nutritional Guidance Concepts" database, which incorporates ontology-based terminology. This section can be scrolled to view both today’s values and 1-month previous values. Using this information as a reference, the nationally registered dietitian can make reports, comments, and/or suggestions in the text-input screen at the left.

Evaluation of the system’s usefulness
The response forms are shown in Appendix 1. Figure 4 shows the test professionals’ response forms filling-out times. Despite the fact that the test professionals using this system had much more client information than did those not using it, the system lowered times for one novice by 1 minute and 14 seconds, or 6.8%; for the other novice by 13 minutes and 39 seconds, or 44.5%; and for the expert by 19 minutes and 27 seconds, or 32.4%, for an average of 26% reduction. The expert took longer than did the novices to fill out the response forms.

Among the nutritional guidance items, one novice and the expert focused especially on "Diabetes Exchange Lists" and the other novice and the expert on "Calorie Intake Amounts." Cluster analysis of the guidance on the response forms showed the Canberra distance between the novices as 1 and that of the expert as 17.8 when not using the system and 4.9 when using it, a reduction of 12.9, and a decrease between the second novice and the expert from 16.6 to 8.0. This distance was thus reduced by 8.6 using this system.

Discussion
System development
Ontology-based extraction of nutrition management terminology was able to clarify the relationships between terms, arrange them in categories, and capture and organize their meanings. Linking categories in this way will make it possible to share information, update data, and save space. In addition, using ontology-based systems in nutrition management may facilitate collecting and organizing the terms of daily work, yield new conceptual knowledge in nutrition management, and may likely become the standard rule for nationally registered dietitians. Existing computer systems in actual use for this purpose often merely evaluate inputted client diet records and then display only the diagnostic results on the screens. In contrast, this new system shows records dynamically and over time based on a standard set of categories derived from the guidelines. It also allows comparisons of results using colors and signs. The test professionals highly praised this novel functionality. The display section that provides nutritional guidance suggestions based on the Nutritional Guidance Concepts database is a function unavailable in existing food services applications and similar dedicated systems. It will be particularly useful for new nationally registered dietitians who need to provide clients with nutritional guidance.

Filling-out times
We considered some factors that might influence test professional filling-out times depending on whether they were using the system: client-recorded meal times, food details, per-serving amounts, etc. The Response Form has 21 items except body weight and SMBG. Nationally registered dietitians who use the system can concentrate on nutritional guidance tailored to each client. We were concerned that novices might require more time to collect dietary information from numerous assessment items for each client, perform assessments, and sift through and organize the results. However, using this system, the test professionals spent less time filling out response forms for the nutritional guidance of individual clients, because the details displayed with the system enabled speedy, accurate assessment of individual clients’ eating details. Furthermore, as they filled out their response forms, the test professionals could also refer to the nutrition problematic points and suggested comments the system displayed.

The results also showed that the expert took longer to fill out the response forms. An expert dietitian, more than a novice, is likely to rely on tacit knowledge acquired through work experience rather than explicit knowledge. This might mean they need more time to record their thoughts.

In the present study, we found that the expert’s comments on nutritional guidance, but not in those of the 2 novices, sometimes involved praise and empathy to the client. In the future, we plan to conduct even more ontology based extractions of tacit knowledge used by experts in their nutritional guidance work and associate our findings with the present system, thereby providing more needed support to all nationally registered dietitians.

Guidance contents recorded by test professionals
The terms the test professionals preferred are shown in Appendix 2. Cluster analysis was performed on those terms, and the dissimilarity of the nutritional guidance
content was evaluated using Canberra distance. The initial distances between both novices and the expert were similar, meaning the novices were close to one another. Conversely, when this system was being used, the distance between one novice and the expert narrowed significantly more than did that between the other novice and the expert, although they were remarkable in both cases.

As this implies, when the system was employed, part-of-speech information for client-guidance content became more similar among the test professionals, showing the accuracy of the ontology. I.e., even when a novice lacks explicit knowledge, referring to the suggested comments displayed on the screens by the system, which support a novice with terms and phrasing that are difficult to understand and remember by oneself, the nutritional guidance content provided becomes more similar to that provided by an expert. As the Canberra distance also became closer, we plan future studies to investigate whether or not the nutritional guidance contents included in this system actually enhances the outcomes of clients who need support regarding nutrition and food, providing a “bottom-up” approach to nutrition guidance for new nationally registered dietitians.

The major limitations in this study were the sample size, in that there were only 3 nationally registered dietitians and each of them had different numbers of years of experience. This study showed a 100% response rate, a 90% confidence interval, and a 21.1% sampling error. To clarify and demonstrate the usefulness of the system, investigation a of a larger population would clearly demonstrate that this system will likely help nationally registered dietitians make more accurate empirical judgments in their guidance consults.

In conclusion, using the four texts of the guidelines, ontology-based extraction was made of 252 terms concerning nutrition management. These were placed in 6 databases, and a nutrition management support system comprised of two elements, the CRS system used by clients and nationally registered dietitians alike and a NGS system was developed. The test professionals for the system in the study were two new nationally registered dietitians with relatively scant experience and one expert nationally registered dietitian with extensive experience. Measurements were made of the times required to fill out response forms with nutritional guidance for clients. Canberra distance, calculated by means of cluster analysis, was used to infer dissimilarity in this content, and the usefulness of the system was evaluated on that basis. It was found that using the system reduced time required to fill-out the response forms for all test professionals. Based on these results, it is likely that the system will be of assistance in the development of nutritional guidance reports and documents used by nationally registered dietitians. Furthermore, Canberra distance of content provided by these novices and this expert alike showed that the distances became more similar than those with

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**Appendix 2.** Test professional’s terms
not using the system. Thus, the system can assist in boosting, in a "bottom-up" fashion, the guidance-related abilities of new nationally registered dietitians.

Acknowledgments

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References