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Research article

Reducing anxiety and enhancing satisfaction in thyroid patients with DietLens application during radioactive iodine therapy: A quasi-experimental study

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ABSTRACT

Hyperthyroidism and thyroid cancer significantly impact health, and often require Radioactive Iodine (RAI) therapy. Anxiety is common in patients undergoing RAI, particularly related to dietary compliance. This study aimed to assess the effectiveness of the mobile health application, DietLens in reducing anxiety and increasing satisfaction in patients preparing for RAI therapy, focusing on low-iodine diet (LID). A quasi-experimental study was conducted in a Singapore tertiary hospital outpatient department from March 13, 2019 to March 27, 2020, involving patients scheduled for their first RAI treatment. Participants were divided into a control group receiving standard care and an intervention group using DietLens alongside standard care. Anxiety levels were assessed using the Zung Self-Rating Anxiety Scale, and satisfaction levels were measured through self-reported questionnaires. In the study, 56 participants were initially divided into control (n = 28) and intervention (n = 28) groups. After accounting for dropouts, 50 participants finished the study, with each group comprising 25 individuals. Anxiety levels were similar between groups pre-intervention. Post-intervention, the intervention group displayed a significant decrease in anxiety levels compared to the control group (independent *t*-test: t (48) = 2.50, p = 0.02). The multivariate linear regression analysis indicated that being in the intervention group was significantly associated with a decrease in post-intervention anxiety score (β = −4.03, 95 % CI: −7.33 to −0.72, p = 0.02). Fisher's Exact Test revealed a borderline significant difference in satisfaction with educational materials and the overall treatment process, with 100 % of the intervention group expressing satisfaction compared to 80 % in the control group, resulting in a p-value of 0.052 in both instances. DietLens was effective in reducing anxiety and enhancing satisfaction related to RAI therapy preparation, particularly in managing a LID, highlighting a beneficial role for digital interventions in healthcare settings.

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1. Introduction

Hyperthyroidism and thyroid cancer are significant health concerns that impact a considerable portion of the population. 13.3 %–22.6 % of hyperthyroid patients were also diagnosed with thyroid cancer [1,2]. The management of these conditions often involves complex treatment protocols, among which Radioactive Iodine (RAI) therapy is a prominent option [3]. RAI therapy is a medical treatment that administers a radioisotope which emits radiation that specifically targets the thyroid gland [3]. This therapy is commonly used to treat hyperthyroidism and thyroid cancer. Anxiety is a common issue among patients who are planned for RAI treatment [4]. Patients frequently experience anxiety stemming from uncertainty about treatment efficacy and insufficient knowledge about treatment preparation and processes [5–7]. Specifically, some patients have reported anxiety while adhering to low-iodine diet (LID) due to the lack of knowledge and difficulties in managing this diet [8]. Therefore, innovative methods should be utilized to reduce patients' anxiety towards the treatment process.

To address the challenges of patient anxiety and knowledge gaps in treatment processes, leveraging technology has shown promise. The usage of mobile applications for health monitoring and management has become increasingly popular in recent years [9,10]. Users were found to gain more knowledge and control over their health, which can reduce anxiety levels and increase their satisfaction with the treatment process [11]. Several studies have shown that mobile applications can effectively reduce anxiety symptoms among patients. For example, the mobile application called SuperBetter was found to be helpful in reducing anxiety symptoms among individuals with depressive symptoms [12]. Implementing a smartphone application into the usual cognitive-behavioral therapy for children diagnosed with anxiety disorders was also shown to improve the efficacy of the therapy, leading to faster improvements and better self-control among patients [13]. Mobile applications were also found to be useful in reducing anxiety among cancer patients [14].

In addition to reducing anxiety, mobile applications have been shown to enhance the overall care experiences and increase patients' satisfaction levels. For instance, a mobile application used to track wound healing was found to be useful in managing patients' wounds and increasing their confidence in wound management [15]. Mobile health applications have also been found to be helpful in managing cancer conditions and providing feedback on patients' health to update their physicians without the need for face-to-face consultations [16]. The effectiveness of mobile applications in managing post-traumatic stress disorder was found to vary based on the participants' smartphone ownership status, with smartphone owners expressing greater satisfaction with the application [17]. Similarly, a mobile application used to send reminders and provide essential information to patients with diabetes was found to be useful and well-received by the participants [18]. Despite the benefits of mobile health applications, there is a lack of studies investigating how mobile health applications such as DietLens, can aid patients in preparing for RAI therapy and how they can enhance patients' satisfaction with the treatment process.

While the effectiveness of mobile applications in alleviating anxiety and improving patient care is well documented, there is a distinct lack of research on their influence on specific dietary compliance, especially in the context of RAI therapy. Adhering to a LID is an essential preparatory step for patients undergoing RAI therapy [8]. This adherence is frequently challenging due to the dietary limitations and the necessity for precise information [8]. Non-compliance with LID can significantly impact the success of RAI therapy, potentially leading to suboptimal treatment outcomes [19]. Moreover, the stress associated with managing such a restrictive diet, particularly in the absence of sufficient support or guidance, can exacerbate the treatment experience for patients. This situation underscores an important opportunity for intervention, where mobile health applications could be instrumental not only in offering dietary advice and support but also in mitigating the anxiety related to adhering to LID. Therefore, this study seeks to bridge this gap by exploring the role of a particular mobile application, DietLens, in assisting patients with maintaining a LID and evaluating its effect on reducing anxiety levels associated with this aspect of preparing for RAI therapy.

The uniqueness of DietLens stems from its distinctive attributes. DietLens leverages artificial intelligence to discern appropriate food choices for users; DietLens employs a visual dietary tracking system powered by sophisticated image recognition algorithms to identify various food items [20]. While its initial purpose was calorie calculation, DietLens can be tailored to cater to the specific requirements of various user groups, such as patients undergoing RAI therapy. The prevailing mobile health applications in existing literature often lack precise dietary recommendations, thus creating an opening for the development of more specialized applications such as DietLens in this domain.

Addressing the aforementioned gaps, this study pursued three objectives. Its primary objective was to investigate the efficacy of DietLens in reducing anxiety levels among its users. In addition, the secondary objectives were to evaluate the satisfaction levels of participants towards standard care and to evaluate users' satisfaction with DietLens.

2. Materials and methods

2.1. Ethical considerations

The study was approved by the Centralized Institutional Review Board in Singapore (ref: 2018/2926). Written informed consent was obtained from the participants. To ensure the confidentiality of participant details and promote voluntary participation, anonymity was maintained throughout the study; participants were informed that their decisions to decline participation would not impact their medical treatments in any way.

2.2. Eligibility criteria

The study was conducted at Department of Nuclear Medicine and Molecular Imaging, an outpatient department located within a tertiary hospital in Singapore. This center provides RAI therapy for patients with hyperthyroidism and thyroid cancer. The inclusion criteria for the study were patients who were 21 years old or older, fluent in English (speaking, reading, and writing), owned a smartphone (for the intervention group only) with access to WIFI or data, and had confirmed their intention to undergo RAI therapy for the first time. The exclusion criteria were patients who were not undergoing RAI therapy for the first time and those with cognitive, visual, or hearing impairments.

2.3. Study design

The research was conducted between March 13, 2019 to March 27, 2020, utilizing a quasi-experimental parallel design. In this design, participants were allocated to either the intervention group or the control group. Neither the participants nor the researchers were blinded in this study. The study team identified patients who had been confirmed to receive their first RAI treatment during their consultation with the doctor. The team then recruited potential participants that matched the study's eligibility criteria and those who agreed to participate were asked to provide written consent.

Participants recruited on even weeks were allocated to the control group, receiving only standard care which involved a treating physician explaining the RAI treatment process and providing them with an information sheet containing pre-treatment preparation and post-treatment instructions for their reference. Participants recruited on odd weeks were allocated to the intervention group. In this group, participants received both the DietLens and standard care. They were guided on how to download and utilize the application on their phones. The data on anxiety levels were collected pre- and post-intervention while satisfaction surveys were collected post-intervention only, following at least three weeks from when their physicians confirmed their requirement for RAI therapy. The duration of three weeks was decided because this is the duration needed for the radioisotope to be delivered to the department prior to patient administration. Fig. 1 presented an illustration of the study design.

2.4. Sample size

The sample size was expected to be 50 as conducting a pilot trial with at least 50 participants can offer initial evidence regarding the efficacy of an intervention, while also being manageable in terms of scale [21]. Earlier pilot investigations assessing the effects of mobile applications on health outcomes or adherence to treatments also utilized sample sizes varying between 40 and 80. This range is chosen to confirm the feasibility of the approaches prior to advancing to randomized controlled trials [22,23].

2.5. DietLens

For this study, a mobile health application called DietLens was utilized. DietLens was created as a research project at a local university [20]. Using food recognition technology, the initial intent of the system was to tally the calories through analyzing images

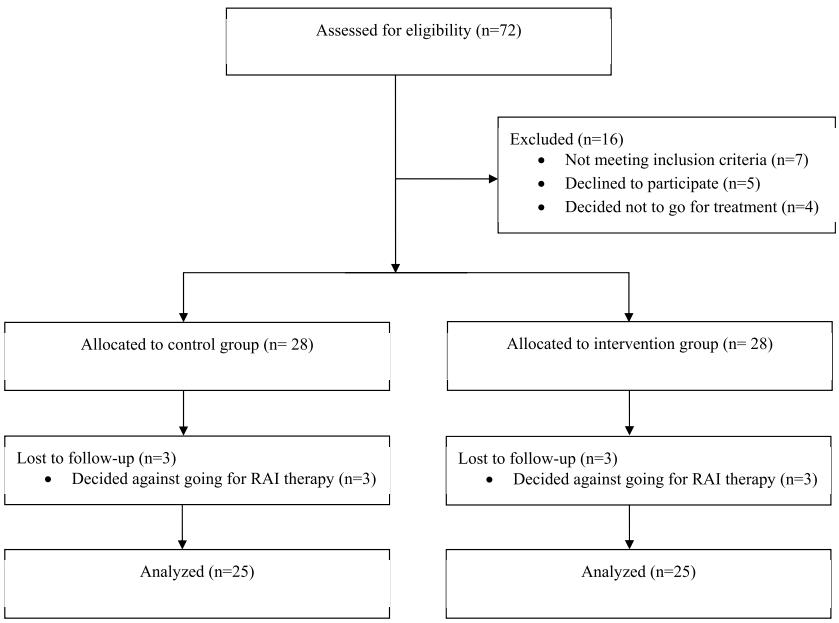

Fig. 1. Flow diagram of participant recruitment.

provided by users. In this study, the DietLens was modified by the research team members who assessed all the labelled food products available in DietLens and categorized each of them based on their iodine content levels. The content levels were validated by a nuclear medicine physician, ensuring that the information presented in DietLens was accurate. A DietLens user could ascertain the iodine content of a food product by capturing a picture of the food into the application. Upon submission of the image, the DietLens software generated a list of possible food items for the user to select from. The user then selects the appropriate food items that correspond to the images submitted earlier. The mobile application displays a tick (✓) on the screen if the food item is deemed to be low in iodine content, indicating that it is recommended for consumption. Conversely, a cross (X) is displayed if the food item is considered high in iodine content, indicating that it should be avoided. Fig. S1 in supplementary file depicted how the modified DietLens in this study operated.

2.6. Measurements

Besides demographic profiles, participants were assessed for their anxiety and satisfaction levels. Zung Self-Rating Anxiety Scale (SAS) was utilized to assess participants' anxiety level [24]. The questionnaire consists of 20 items and utilizes a 4-point Likert scale to assess individuals for anxiety. SAS is a well validated scale which is widely used in studies examining anxiety levels among participants [25,26]. The internal consistency of SAS is 0.82 [27]. Elevated scores on the questionnaire indicate greater levels of anxiety. The normal range is between 20 and 44, while 45–59 indicates mild to moderate anxiety levels. Scores ranging from 60 to 74 indicate moderate to severe anxiety levels, while scores above 75 represent an extreme level of anxiety [24].

To assess the satisfaction of participants who received standard care, a self-administered questionnaire with four items was used, which included a 5-point Likert scale ranging from "very satisfied" to "very dissatisfied." The questionnaire covered: Q1. Explanation of the treatment process; Q2. Explanation and educational materials given for preparation (low-iodine diet, stopping of medication) for treatment; Q3. Clarity of instructions for low-iodine diet; Q4. Overall satisfaction towards the entire treatment process (from first consultation to preparation (low-iodine diet) to the treatment date). In addition, participants in the intervention group were asked to complete another 4-item self-reported questionnaire using a 5-point Likert scale (ranging from strongly agree to strongly disagree) to assess their satisfaction with using DietLens. This questionnaire also contained two open-ended questions which asked users if they would recommend DietLens to other patients undergoing RAI therapy and provide any recommendations to improve the application. The construction of these satisfaction surveys was influenced by the satisfaction scales from the studies of McMillan et al. [28] and Conaglen et al. [29] as these studies specifically focused on the satisfaction of patients with thyroid disorders towards their treatment regimes. Initially, XY formulated the questions. Subsequently, she consulted other authors, F, SMY, WY for face validity to ensure the questionnaire items aptly addressed the study's variables [30]. Following this, XY sought feedback from XC and SH, who possess specialized expertise in patient satisfaction in clinical settings, to affirm the content validity. Content validity is crucial as it facilitates the elicitation of more pertinent and accurate responses in relation to the research objectives [30].

2.7. Statistical analysis

To assess the deviation of the data from normality, the researchers utilized the Kolmogorov-Smirnov test (see Table S1 in supplementary file). Following this assessment, it was determined that the variables exhibited a normal distribution, thus facilitating the application of parametric inferential analysis. Data cleaning and analysis were performed using Python, version 3.9.12, with the procedure of replacing missing values by the mean value of the respective column for anxiety scores of each group. Since the continuous variables followed a normal distribution, the authors opted to use the mean for imputing missing values, because it represents the central tendency of the data distribution. The authors also replaced missing values for satisfaction levels in each group with the mode of the respective column. The choice of using mode for imputing missing satisfaction levels is attributed to the ordinal nature of the data. Mode captures the most frequently occurring response in this type of data, offering a realistic estimate of the satisfaction levels.

Descriptive analysis was employed to elucidate the characteristics of the demographic and satisfaction data. A comparison of the baseline demographic characteristics between the control and intervention groups was carried out to ascertain the homogeneity of the participant groups. Within-groups differences in anxiety levels were evaluated using paired *t*-test, while independent *t*-test was utilized to assess differences between the two groups. The categorization of satisfaction levels was divided into "Satisfied" and "Dissatisfied". The former encompassed responses of "Very satisfied" and "Somewhat satisfied", whilst the latter included "Neither satisfied nor dissatisfied", "Somewhat dissatisfied", and "Very dissatisfied". In examining these satisfaction variables, the application of Fisher's Exact Test was necessitated due to the presence of minimal cell counts (fewer than five) within the contingency table (See Table 5). A two-tailed p-value of less than 0.05 was considered as statistically significant. Answers to the open-ended questions were analyzed using content analysis. Multivariate linear regression was used to calculate the coefficient of the intervention effect on anxiety, adjusting for age, sex, race, and diagnosis. Prior to this analysis, Variance Inflation Factor was measured to assess multicollinearity among these key variables. Given that this was the initial application of the SAS and satisfaction scale among this sample group in the current context, the authors chose to determine the internal reliability (Cronbach's alpha) for both the anxiety scale and the satisfaction scale.

2.7.1. Item analysis for scale reliability for Zung Self-Rating Anxiety Scale (SAS)

Considering the central role of the anxiety variable in this study, the authors extended their analysis beyond calculating Cronbach's alpha for the SAS. They employed item-total correlation analysis and assessed the impact of item deletion on Cronbach's alpha to

enhance their scale's reliability. Item-total correlation analysis was employed to determine how each individual item correlated with the overall construct, with higher correlations indicating greater congruence with the scale's aggregate, thereby contributing to its internal consistency [31]. Concurrently, the authors conducted Cronbach's alpha evaluations upon item deletion to assess the impact of each item on the scale's overall reliability. This step involved recalculating Cronbach's alpha after sequentially omitting each item, a method informed by Kopalle and Lehmann [32], who highlighted the significant influence of item removal on Cronbach's alpha, especially pertinent in smaller sample sizes. These methods collectively provided a comprehensive assessment of the scale's internal consistency and reliability.

3. Results

A total of 72 individuals were contacted to gauge their interest in participating in the research endeavor. Out of this initial pool, 56 individuals expressed their willingness to partake in the study. However, six among them subsequently opted not to proceed with RAI therapy, thereby choosing to withdraw from the study. Ultimately, a cohort of 50 individuals successfully completed the RAI therapy as prescribed. The participants were stratified into two distinct groups: 25 individuals were allocated to the intervention group, while the remaining 25 were assigned to the control group, as illustrated in Fig. 1.

The calculation of Cronbach's alpha for the Zung Self-Rating Anxiety Scale yielded values of 0.62 prior to the intervention and 0.67 following the intervention, indicating a moderate level of internal consistency for this scale. In examining the scale reliability in detail, the authors found insights about items exhibiting negative correlations with total scores within the anxiety scales. Before the intervention, items 9 and 19 showed negative correlations with the total score, being −0.02 and −0.03 respectively. Post-intervention, items 5 and 13 also demonstrated negative item-total correlations, recorded at −0.03 and −0.05. Such negative correlations imply a potential inverse relationship between these items and the overall concept measured. Nonetheless, omitting these items led to only slight improvements in Cronbach's alpha: for item 9, it increased to 0.65; for item 19, to 0.65 before the intervention; for item 5, to 0.70; and for item 13, to 0.70 after the intervention. These findings suggested that although these items inversely correlated with the total score individually, their overall impact on the scale's reliability was relatively small. Consequently, the authors opted not to exclude any items from the anxiety scale in their final evaluation of the scale. Additional details on item-total correlation and the effects of item removal on Cronbach's alpha were provided in the supplementary material (Tables S2 and S3).

The Cronbach's alpha for the satisfaction scale related to the standard process was 0.86, signifying good internal consistency, whereas the satisfaction scale pertaining to DietLens demonstrated a Cronbach's alpha of 0.60, indicating a moderate level of internal consistency.

3.1. Demographic profiles

Among the 50 participants, 66 % (n = 33) were females. Most of the participants were Chinese (n = 38, 76 %). The mean age of the participants was 43.0 ± 12.8 years old. Out of all the participants, 70 % (n = 35) were diagnosed with hyperthyroidism while the rest were diagnosed with thyroid cancer.

According to the data presented in Table 1, the baseline characteristics of participants in both the control and intervention groups exhibited similarity, thus indicating a homogeneity among the study's participants.

3.2. Objective 1: to investigate the efficacy of DietLens in reducing anxiety levels among its users

To evaluate the differences in anxiety scores among the control and intervention groups, paired *t*-test was employed. In the control group, the initial mean anxiety score was recorded at 35.0 ± 5.55. Following the intervention, this figure marginally rose to 36.5 ± 5.25, although this increase was not deemed statistically significant (paired *t*-test: t (24) = −1.78, p = 0.09). Conversely, in the intervention group, the initial anxiety score stood at 32.8 ± 5.61, and post-intervention, it slightly decreased to 32.6 ± 5.98. This change, however, did not reach statistical significance (paired *t*-test: t (24) = 0.30, p = 0.77).

Independent *t*-test was applied to evaluate the disparities in anxiety scores between the control and intervention groups. When comparing the groups before the intervention, there was no significant difference in anxiety scores (independent *t*-test: t (48) = 1.36, p

Table 1
Demographics of participants (N = 50).

Variables	Control Group (n = 25)	Intervention Group (n = 25)	p-value
Age (years)	43.1 ± 12.9	42.8 ± 12.9	0.94
Sex			
Female	16 (64.0 %)	17 (68.0 %)	1.00
Male	9 (36.0 %)	8 (32.0 %)	
Race			
Chinese	18 (72.0 %)	20 (80.0 %)	0.74
Non-Chinese	7 (28.0 %)	5 (20.0 %)	
Diagnosis			
Hyperthyroidism	19 (76.0 %)	17 (68.0 %)	0.75
Thyroid Cancer	6 (24.0 %)	8 (32.0 %)	

= 0.18). However, following the intervention, the anxiety scores in the intervention group were significantly lower compared to those in the control group (independent *t*-test: t (48) = 2.50, p = 0.02) (See Table 2).

Variance Inflation Factor analysis revealed low multicollinearity among the key variables, suggesting no concerns regarding multicollinearity in the multivariate linear regression analysis (See Table 3).

In the multivariate linear regression model after adjusting for age, sex, race, and diagnosis, being in the intervention group was significantly associated with a decrease in the post-intervention anxiety score. As shown in Table 4, the coefficient (β) for the intervention group was −4.03 (95 % Confidence Interval: −7.33 to −0.72, p = 0.02), indicating that participants in the intervention group had a decrease of 4.03 units in their post-intervention anxiety score compared to those in the control group, holding other variables constant.

Although not statistically significant, being female was associated with an increase of 1.85 units in the post-intervention anxiety score compared to being male, when all other variables in the model are held constant (95 % Confidence Interval: −1.62 to 5.33, p = 0.29).

3.3. Objective 2: to evaluate the satisfaction levels of participants towards standard care

Table 5 presents the control group's satisfaction survey outcomes regarding standard care. A majority of them, 92 % (n = 23), expressed satisfaction with the explanations provided by their attending doctor about the treatment process (Q1), and 68 % (n = 17) were satisfied with the clarity of the LID instructions (Q3). In comparison, in the intervention group, 100 % (n = 25) reported satisfaction with the doctor's explanation of the treatment process (Q1), and a higher proportion, 88 % (n = 22), expressed satisfaction with the clarity of LID instructions (Q3).

Regarding the satisfaction with the educational materials for the LID (Q2), 80 % of the control group participants (n = 20) expressed satisfaction, whereas all participants in the intervention group (n = 25) reported satisfaction. Fisher's Exact Test showed a borderline significant difference in satisfaction levels for these educational materials, favoring the intervention group over the control group, with a p-value of 0.052. As for the overall satisfaction with the entire treatment process (Q4), the intervention group reported complete satisfaction (n = 25, 100 %), compared to 80 % satisfaction in the control group (n = 20). This also reflected a near-significant higher level of overall treatment satisfaction in the intervention group as per Fisher's Exact Test (p = 0.052). However, for other aspects of satisfaction surveyed, no significant differences were observed between the two groups, as detailed in Table 5.

3.4. Objective 3: to evaluate users' satisfaction with DietLens

For questions specific to DietLens usage, an overwhelming group of participants reported that they agreed that they would like to use this application again (n = 16, 64 %). 64 % of participants in the intervention (n = 16) reported that the application provided valuable information regarding LID. Out of all the participants in the intervention group, 72 % of them (n = 18) reported that the application was easy to use and 56 % of them (n = 14) reported that they were satisfied with the application's functions.

For the open-ended questions, 72 % (n = 18) would recommend DietLens to patients who will be receiving RAI therapy. However, two of them (8 %) shared that DietLens might be complicated for those who were not well-versed in using smartphones. These individuals provided suggestions for improvement for DietLens such as having the option to choose which language to view the application in and making the tabs more prominent and easier to read.

4. Discussion

The study undertaken from March 13, 2019 to March 27, 2020, explored the effectiveness of a mobile health application named DietLens in alleviating anxiety in patients undergoing RAI therapy, at least three weeks from when their physicians confirmed their requirement for RAI therapy. Additionally, it aimed to evaluate participant satisfaction with standard care and the DietLens application. Despite no significant differences being observed within each group before and after the intervention, an increase in anxiety scores was noted in the control group, while the intervention group showed a decrease in their anxiety scores. Significant differences were observed in anxiety reduction between the control and intervention groups post-intervention. The multivariate linear regression analysis revealed that the coefficient for the intervention group was −4.03, which indicated that participants in the intervention group had a decrease of 4.03 units in their post-intervention anxiety score compared to those in the control group, holding other variables constant. Moreover, sex appeared to play a role in anxiety levels post-intervention. Specifically, being female was correlated with an increase of 1.85 units in the post-intervention anxiety score compared to being male, albeit this was not statistically significant.

Table 2
Comparison of anxiety scores within and between comparison groups.

	Control Group (n = 25)	Intervention Group (n = 25)	t-statistic (Independent T-Test)	p-values
Pre-intervention, mean ± SD	35.0 ± 5.55	32.8 ± 5.61	1.36	0.18
Post-intervention, mean ± SD	36.5 ± 5.25	32.6 ± 5.98	2.50	0.02*
t-statistic (Paired T-Test)	−1.78	0.30		
p-values	0.09	0.77		

SD=Standard deviation, *p-value <0.05.

Table 3
Variance Inflation Factor analysis for assessing multicollinearity among age, gender, race, and diagnosis variables.

Variables	Variance Inflation Factor
Age	1.03
Sex	1.02
Race	1.11
Diagnosis	1.11

Table 4
Effect of DietLens intervention on anxiety score after adjusted for diagnosis, age, sex, and race (N = 50).

	Coefficient (β)	95 % CI (Lower)	95 % CI (Upper)	p-value
Group (Intervention)	−4.03	−7.33	−0.72	0.02*
Age	−0.07	−0.20	0.06	0.29
Sex (Female)	1.85	−1.62	5.33	0.29
Race (Non-Chinese)	0.24	−3.81	4.30	0.90
Diagnosis (Thyroid Cancer)	−0.28	−4.14	3.58	0.88

CI=Confidence Interval; *p-value <0.05.

Table 5
Satisfaction comparison between Control and Intervention Groups towards standard care (N = 50).

Question: Answer	Control Group (n = 25)	Intervention Group (n = 25)	p-value
Q1: Satisfied, n (%)	23 (92 %)	25 (100 %)	0.49
Q1: Dissatisfied, n (%)	2 (8 %)	0 (0 %)	
Q2: Satisfied, n (%)	20 (80 %)	25 (100 %)	0.05 ˆ
Q2: Dissatisfied, n (%)	5 (20 %)	0 (0 %)	
Q3: Satisfied, n (%)	17 (68 %)	22 (88 %)	0.17
Q3: Dissatisfied, n (%)	8 (32 %)	3 (12 %)	
Q4: Satisfied, n (%)	20 (80 %)	25 (100 %)	0.05 ˆ
Q4: Dissatisfied, n (%)	5 (20 %)	0 (0 %)	

ˆp-value = 0.0502.
Q1. Explanation about treatment process.
Q2. Educational materials.
Q3. Clarity of instructions for low-iodine diet.
Q4. Overall satisfaction towards the entire treatment process.

Participants in the intervention group also demonstrated a marginally higher level of satisfaction with the education materials for Low-Iodine Diet (LID) and the overall treatment process. The majority found DietLens easy to use and would recommend it to others receiving RAI therapy, though some suggestions were made to improve the accessibility and language options.

Though not reaching statistical significance, the control group, who were not recipients of the intervention, exhibited an increase in anxiety from the beginning to the end of the study, mirroring trends seen in established research. In many health-related scenarios, uncertainty can significantly amplify stress and anxiety. This effect is more pronounced in situations where individuals must deal with complex health directives, like dietary prescriptions, without adequate guidance or support [33]. The control group, in particular, demonstrated this effect, as they did not have access to additional dietary information from DietLens, which could have provided instant answers to reduce dietary uncertainty. Moreover, the inability to tolerate uncertainty, characterized by discomfort with ambiguity and potential negative outcomes, is strongly linked to anxiety disorders. Such intolerance can aggravate anxiety, especially when there is uncertainty in following medical prescriptions [34]. This might explain why participants in the control group, despite having received instructions and advice from their physicians, continued to experience anxiety regarding their dietary choices. While the dietary guidance from their doctors and the provided instruction sheets might have been comprehensive, they could have been challenging for participants to remember due to the volume and complexity of the instructions. Consequently, these participants might perceive this information as insufficient for their needs. Hence, the absence of clear, understandable guidance in medical dietary management can escalate anxiety and stress among patients, underscoring the critical need for easy-to-use tools and applications to aid in effective diet management [35].

Individuals in the intervention group experienced a decrease of 4.03 units in their anxiety scores after the intervention, compared to those in the control group, when the effects of other factors (like age, sex, race, and diagnosis) are taken into account. The effectiveness of mobile applications in alleviating patient anxiety during medical procedures has been previously documented in studies [12,14]. DietLens helped to alleviate anxiety by providing quick access to information and reducing wait time patients typically experience when using traditional channels like hospital hotlines or clinic consultations [36]. By offering patients access to information about permissible and prohibited foods before RAI therapy, DietLens equipped patients with the necessary knowledge and

confidence to manage their diet during this phase, resulting in lower anxiety levels compared to those in the control group.

According to the linear regression analysis, female participants had a 1.85-unit higher post-intervention anxiety scores than male participants, although this difference was not statistically significant. This observation aligns with existing literature that underscores the disparity in anxiety disorders between the two sexes. In clinical settings, women have been reported to exhibit heightened severity in anxiety symptoms compared to men [37]. Similarly, Vetter et al. identified an increased presence of psychological and somatic symptoms of anxiety in female subjects [38]. These studies collectively provide a context for the heightened anxiety levels observed in women in the current study, suggesting that women tend to experience greater anxiety than men. Consequently, this underscores the importance of recognizing and addressing sex-specific nuances in anxiety, reinforcing the need for sex-sensitive treatment strategies and support.

In the study, the intervention group demonstrated a higher level of satisfaction with the overall treatment process compared to the control group. This increased satisfaction is likely attributable to their enhanced understanding of the procedures or treatments they were undergoing, enabling them to make more informed decisions and thereby improving their overall treatment experience [39]. A key factor in this improved satisfaction was their familiarity with the LID, facilitated by the DietLens. All participants in the intervention group reported satisfaction with these materials, a stark contrast to the control group. This difference, while near-statistically significant, highlights the potential impact of educational support tools like DietLens. DietLens effectively equipped users with crucial knowledge and confidence for RAI therapy preparation, influencing their decision-making process positively. The strong endorsement of DietLens by participants for its valuable information on LID further underscores its utility. Conversely, the control group's restricted access to such information likely contributed to their lower satisfaction levels.

A minority of DietLens users mentioned that they would not use the application again, with the reason being that the only language available for the interface was English and the tabs were not visibly clear to them. Similar concerns were expressed by various studies [40–42]. Hence, mobile health applications developers should pay attention to the age groups of the targeted application users and to also include other languages to ensure functionality of it.

4.1. Innovations and implications of findings

The innovative exploration of the mobile health application, DietLens, in mitigating anxiety among patients undergoing RAI therapy, demonstrates a novel approach from pre-intervention to post-intervention phases. This study highlights the application's effectiveness in reducing anxiety and enhancing satisfaction levels among participants by providing expeditive access to essential dietary information, thereby equipping them with the confidence to manage their diets effectively. DietLens represents a significant shift away from conventional patient education and anxiety management methods, such as hospital hotlines or clinic consultations, towards a more immediate and user-friendly digital solution. The findings underscore the importance of integrating digital tools like DietLens in medical procedure preparation protocols to promote patient engagement and improve overall treatment experiences. This emphasizes the utility of mobile applications in bridging information gaps inherent in traditional consultations and advocates for a digital-centric approach in healthcare practices, with a call for further research to optimize such interventions in diverse clinical settings and assess their long-term impacts.

4.2. Limitations and strengths

Limitations of this investigation primarily pivot around the quasi-experimental design, which harbors a potential for selection bias due to non-equivalent groups, possibly affecting the internal validity of the findings [43]. Conducted in a single center, the study's findings may lack generalizability to other settings or populations. Additionally, the relatively small sample size is a key limitation, as larger samples could enhance the reliability and generalizability of the results. The relatively short follow-up duration limits the assessment of long-term outcomes, while the oversight of controlling other potential confounding variables such as comorbidities or medications might have influenced the results. Moreover, a notable limitation is the moderate internal consistency of the Zung Self-Rating Anxiety Scale used, as indicated by a Cronbach alpha lower than 0.70, which is particularly concerning for the measurement of anxiety, the central variable of the study. This may affect the robustness of the anxiety-related findings. The use of the anxiety scale in this study, despite its established utility, has an inherent inability to differentiate between state and trait anxiety when compared to the State-Trait Anxiety Inventory [44], further contributing to concerns regarding the precision of the anxiety measurement. Another significant limitation is the absence of a robust tracking system to monitor participant engagement with the DietLens application. This study relied on the study participants' self-reporting to assess adherence to application usage. As a result, this introduces potential biases and limits the precision of our findings, especially regarding the application's effectiveness in aiding adherence to a LID and reducing anxiety levels. The limitations posed by self-reported data and the lack of objective verification mechanisms highlight areas for improvement in future research designs.

On the flip side, the study showcases several strengths including comparable demographic characteristics across both groups of participants, which lends credence to the attribution of observed outcome disparities to the intervention itself. The demonstrated homogeneity among participants, even without formal randomization, effectively emulates a randomized effect, enhancing the internal validity of the findings. The high reliability score associated with satisfaction towards standard care indicates a valid representation of the concept being measured. These strengths, coupled with the uniformity among participants, augment the internal validity of the study, highlighting the potential impact of DietLens on anxiety reduction during the preparatory phase of RAI therapy, thus making a compelling case for further exploration in diverse clinical settings.

5. Conclusions

This study highlights the significant potential of mobile applications like DietLens in mitigating anxiety among patients preparing for RAI therapy. Despite certain limitations, the reduction in anxiety and increased satisfaction reported by the intervention group advocate for the integration of digital interventions in healthcare settings. The findings align with the broader discourse on employing technology to enhance patient education and engagement, highlighting the importance of further research in diverse clinical settings to corroborate and expand upon these findings. The promising trajectory delineated by DietLens paves the way for exploring digital interventions as viable aides in improving patient experiences during medical interventions.

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CRediT authorship contribution statement

Xin Yi Seah: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Xiang Cong Tham:** Writing – review & editing, Visualization, Methodology, Formal analysis. **Fazila Aloweni:** Resources, Conceptualization. **Sandra Mei Yu Kua:** Project administration, Investigation. **Wei Ying Tham:** Resources, Conceptualization. **Siew Hoon Lim:** Validation, Software, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e35450.

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