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Evaluating psychological anxiety in patients receiving radiation therapy using smartwatch

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Purpose: Patients undergoing radiation therapy (RT) often experience psychological anxiety that manifests as muscle contraction. Our study explored psychological anxiety in these patients by using biological signals recorded using a smartwatch.

Materials and Methods: Informed consent was obtained from participating patients prior to the initiation of RT. The patients wore a smartwatch from the waiting room until the conclusion of the treatment. The smartwatch acquired data related to heart rate features (average, minimum, and maximum) and stress score features (average, minimum, and maximum). On the first day of treatment, we analyzed the participants' heart rates and stress scores before and during the treatment. The acquired data were categorized according to sex and age. For patients with more than three days of data, we observed trends in heart rate during treatment relative to heart rate before treatment (HRtb) over the course of treatment. Statistical analyses were performed using the Wilcoxon signed-rank test and paired t-test.

Results: Twenty-nine individuals participated in the study, of which 17 had more than 3 days of data. During treatment, all patients exhibited elevated heart rates and stress scores, particularly those in the younger groups. The HRtb levels decreased as treatment progresses.

Conclusion: Patients undergoing RT experience notable psychological anxiety, which tends to diminish as the treatment progresses. Early stage interventions are crucial to alleviate patient anxiety during RT.

Keywords: Radiotherapy, Psychological anxiety, Heart rate, Biological signals, Smartwatch

Introduction

Radiation therapy (RT) necessitates the precise delivery of prescribed radiation doses, as established in the treatment plan. Any deviation from the treatment plan can compromise treatment efficacy and result in damage to normal tissues [1,2]. Factors affecting the treatment plan accuracy include mechanical and patient factors. Mechanical factors include the multi-leaf collimator position, beam field size, and beam profiles. These issues are routinely addressed by equipment quality assurance. Patient-related factors, such as breathing patterns, weight loss, and gastrointestinal movement, are managed using techniques such as image-guided radiation therapy, adaptive computed tomography, and controlled fasting to improve accuracy [3,4]. Psychological anxiety is also one of the contributing factors affecting the accuracy of treatment [5].

Survey studies have compared responses to validated questionnaires, such as the Symptom Checklist-90-Revised and Perceived Stress Scale (PSS-10), under both restful and stressful conditions [6,7]. Survey studies have been conducted on the general public to assess psychological anxiety [8,9]. A previous study investigated anxiety in patients before and after RT using a visual analog scale survey [10]. Anxiety research using surveys is a subjective evalua-

tion method that relies on patient self-reporting, which may not fully reflect actual anxiety levels and their impact on treatment positioning errors [11].

Physical or psychological anxiety stimulates the sympathetic nerves of the autonomic nervous system, leading to muscle contraction and stiffness due to increased heart rate (HR), blood pressure, and blood flow [12,13]. Thus, measuring and quantifying psychological anxiety may be an important factor in reducing positioning difficulties and uncertainty caused by muscle contraction. Biological signals, such as photoplethysmography (PPG) and electrocardiography (ECG) signals acquired from fingertip devices, can correlate with human anxiety [14-16]. Modern smartwatches, which are widely used in everyday life, have demonstrated the capability to detect PPG and ECG signals with high accuracy [17,18]. Furthermore, recent studies have measured and analyzed anxiety during rest and daily activities in the general public using smartwatches [19-21].

Therefore, this study aimed to assess the psychological anxiety of patients using smartwatches, which could contribute to errors associated with the RT setup. The patients' psychological anxiety before and during treatment was assessed by calculating the changes in HR and heart rate variability (HRV) using a smartwatch. We evaluated the change in HR as treatment progressed.

Materials and Methods

1. Patients

The study protocol was approved by the Institutional Review Board of Samsung Medical Center (IRB No. 2020-11-162). We obtained signed written research consent from adult patients aged 18 years and older who underwent RT for cervical, breast, prostate, and lung cancers between February 9, 2021, and February 14, 2022. To be eligible for participation in the study, patients must be able to communicate, and RT should have been administered for the first time. Patients who agreed to participate but later canceled treatment, withdrew from the study, or whose data could not be obtained because of wearing errors were excluded (Fig. 1).

2. Data acquisition process

To assess the psychological anxiety of patients undergoing RT, they wore a smartwatch from before to the end of the RT treatment session. The smartwatch used was the Galaxy Watch Active 2 (Samsung Electronics, Suwon, South Korea), which analyzes PPG to calculate HRV. The stress score was obtained by analyzing HRV using an algorithm built into the smartwatch [22], and the HR was calculated using the HRV. Thus, we collected HR and stress scores from patients before and during daily RT sessions for 3 consecutive days.

The patients arrived in the waiting room 10 minutes before the RT session and wore a smartwatch. The smartwatch was returned after the treatment was completed. Data were extracted using an application linked to the smartwatch and categorized into groups before and during treatment. The acquired data included HR features (average, minimum, and maximum HRs) and stress score features (average, minimum, and maximum scores). The HR and stress score medians were included as eight features for comparison. The unit of HR is beats per minute, and the stress score ranges from 0 to 100.

3. Evaluation

Before and during treatment, the features were calculated using the 5-minute averages of the acquired data, and the two differences were analyzed using the Wilcoxon signed-rank test and paired t-test, according to the normality of the data. The "before treatment" data were in a stable state after arriving at the treatment waiting room, and the "during treatment" data were measured 2 minutes after lying down on the treatment couch. Changes before and during treatment were analyzed using data obtained from the first treatment session, and all participants were categorized by sex and age. Additionally, the patients' HR tendencies according to the treatment process were investigated using HR during treatment relative to HR before treatment (HRtb). All statistical analyses were performed using R Statistical Software (version 3.6.3; The R Foundation for Statistical Computing, Vienna, Austria).

Results

A total of 35 patients consented to participate in the study, and the

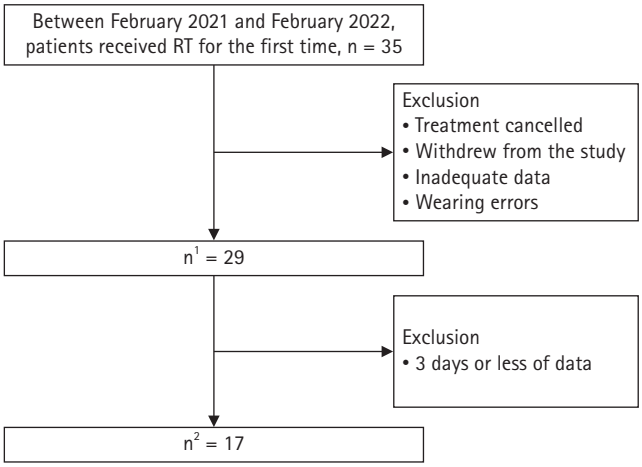

Fig. 1. Patient flow chart. RT, radiotherapy; n^1, patients with at least 1 day of data; n^2, patients with more than 3 days of data.

data from 29 patients were used (Table 1). The average age of patients was 59 years (range, 40 to 80 years), and males (70.1 years) were older on average than females (52.6 years). Using data from 29 individuals, we confirmed changes in features before and during treatment (Table 2). All features showed significant differences, especially those related to HR ($p < 0.001$).

During treatment, six features in the male group and four in the female group were significantly different from those before treatment ($p < 0.05$) (Table 3). When the patients were grouped into ages, older (>59.2 years) and younger group (<59.2 years), seven features in the younger group showed significant differences ($p < 0.01$) (Table 4), while statistical difference were found in four features in the older aged group.

Changes in HRtb were analyzed in 17 patients, with error-free data obtained both before and during treatment over 3 days. As shown in Fig. 2A, the average and median HRtb values decreased as the daily treatment sessions continued. Fig. 2B shows the variations in HRtb in the patients by date.

Table 1. Participant characteristics (n = 29)

Characteristic	Value
Age (yr)	59.2 (40–80)
Male	70.1 (57–80)
Female	52.6 (40–73)
Sex	
Male	11 (37.9)
Female	18 (62.1)
Surgery	15 (51.7)
Chemotherapy	4 (13.8)
Tumor	
Cervical	7 (24.2)
Breast	9 (31.0)
Prostate	4 (13.8)
Lung	9 (31.0)
Modality	
IMRT	10 (34.5)
SBRT	9 (31.0)
3D conformal	6 (20.7)
Proton	3 (10.3)
Tomography	1 (3.5)

Values are presented as median (range) or number (%).
IMRT, intensity-modulated radiation therapy; SBRT, stereotactic body radiation therapy.

Discussion and Conclusion

Patient positioning errors in RT can significantly affect treatment accuracy and, consequently, treatment outcomes. Although state-of-the-art RT techniques, such as image-guided radiation therapy, allow for the monitoring of patient position and anatomy, there is currently no method available for measuring patient anxiety during beam delivery. This study investigated the feasibility of monitoring increased anxiety by obtaining a patient's biological signals that are considered to be related to body stress. The use of smartwatches to measure biological signals has been validated for usefulness and credibility in anxiety evaluation research in daily life [19-21].

Table 2. Evaluation of changes in biological signal features before and during radiation therapy according to all patients

Feature	Before treatment	During treatment	p-value
Heart rate (bpm)			
Minimum	72.39 ± 9.27	82.28 ± 13.98	<0.001
Average	75.41 ± 9.82	85.61 ± 14.36	<0.001
Maximum	79.36 ± 10.21	90.23 ± 14.92	<0.001
Median	76.02 ± 10.80	85.69 ± 15.40	<0.001
Stress			
Minimum	4.72 ± 7.47	18.61 ± 24.34	0.012
Average	6.70 ± 9.25	22.10 ± 26.94	0.012
Maximum	9.60 ± 12.07	25.70 ± 29.19	0.012
Median	5.57 ± 8.43	18.34 ± 28.38	0.037

Values are presented as mean ± standard deviation.
bpm, beats per minute.

Table 3. Evaluation of changes in biological signal features before and during radiation therapy according to sex

Feature	Male			Female		
	Before treatment	During treatment	p-value	Before treatment	During treatment	p-value
Heart rate (bpm)						
Minimum	68.35 ± 10.25	78.87 ± 12.23	0.018	74.86 ± 7.61	84.36 ± 14.56	0.001
Average	71.00 ± 10.71	81.31 ± 12.35	0.016	78.10 ± 8.13	88.24 ± 14.86	<0.001
Maximum	74.69 ± 11.23	84.91 ± 12.53	0.020	82.21 ± 8.32	93.49 ± 15.32	0.001
Median	71.45 ± 11.38	81.73 ± 13.70	0.018	78.81 ± 9.40	88.11 ± 15.87	0.002
Stress						
Minimum	1.36 ± 2.15	21.00 ± 29.39	0.058	6.77 ± 8.72	17.19 ± 20.52	0.083
Average	2.56 ± 3.45	24.64 ± 30.64	0.032	9.23 ± 10.66	20.54 ± 24.28	0.127
Maximum	4.24 ± 4.53	29.25 ± 31.58	0.024	12.87 ± 13.71	23.52 ± 27.40	0.201
Median	2.27 ± 4.53	24.09 ± 32.60	0.052	7.58 ± 9.56	14.83 ± 24.81	0.345

Values are presented as mean ± standard deviation.
bpm, beats per minute.

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Table 4. Evaluation of changes in biological signal features before and during radiation therapy according to age

Feature	Older (> 59.2 yr)			Younger (< 59.2 yr)		
	Before treatment	During treatment	p-value	Before treatment	During treatment	p-value
Heart rate (bpm)						
Minimum	70.37 ± 11.42	78.52 ± 13.98	0.025	74.03 ± 7.43	85.32 ± 14.12	< 0.001
Average	72.57 ± 12.00	81.34 ± 14.42	0.017	77.71 ± 7.65	89.09 ± 14.28	< 0.001
Maximum	75.89 ± 12.35	85.23 ± 14.69	0.015	82.18 ± 7.78	94.30 ± 14.77	0.002
Median	73.08 ± 12.85	81.54 ± 15.45	0.022	78.41 ± 8.95	89.06 ± 15.51	0.001
Stress						
Minimum	3.72 ± 9.34	11.51 ± 18.89	0.236	5.53 ± 6.04	24.39 ± 27.94	0.025
Average	4.66 ± 10.59	14.58 ± 21.89	0.153	8.35 ± 8.32	28.20 ± 30.52	0.033
Maximum	5.86 ± 11.81	18.46 ± 24.33	0.126	12.63 ± 12.18	31.58 ± 33.04	0.065
Median	4.23 ± 8.90	13.15 ± 24.14	0.236	6.66 ± 8.45	22.56 ± 32.39	0.087

Values are presented as mean ± standard deviation.
bpm, beats per minute.

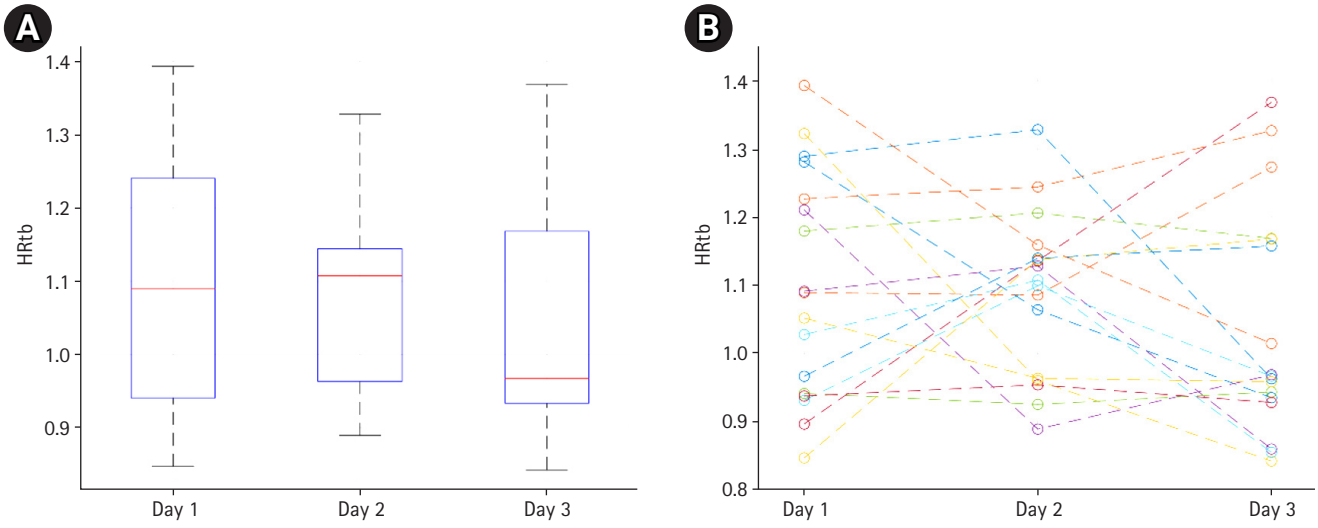

Fig. 2. Boxplot (A) and individual (B) changes in heart rate (HR) during treatment relative to HR before treatment (HRtb) in patients over a 3-day treatment course.

In this study, patient anxiety was assessed by monitoring changes in biological signals before and during RT.

From the analysis of HR and stress scores for the 29 patients who participated in the study, significant differences were observed in all features, where features related to stress scores were $p < 0.05$, and those related to HR were $p < 0.001$ (Table 2). Moreover, both HR and stress scores increased during treatment compared with those before treatment in all patients. Therefore, we demonstrated that biological signals can indicate a patient's anxiety during RT sessions, particularly during the first and second sessions. While patient anxiety after the end of RT was reported through a questionnaire survey in another study [10], we demonstrated that biological signals indicate high stress levels in patients, particularly at the initiation of RT. Stress mitigation measures are necessary before the RT sessions.

As shown in Tables 3 and 4, significant differences were observed among the groups categorized according to sex and age. Six features showed differences between males ($p < 0.05$) and four between females ($p < 0.005$). If the significance level was strictly set at $p < 0.01$, males did not show any differences, whereas females showed differences in the four features. Analysis of different age groups revealed differences in four HR-related features in the older group and six features in the younger group. Similar to the sex analysis, when the standard was strictly set at $p < 0.01$, differences were observed in the four features only in the young group. In summary, significant differences were found in each group when the patients were categorized by sex and age. If the p-value standard was strictly set to $p < 0.01$, changes in features were ob-

served only in females and younger individuals.

Studies by Linden et al. [23] and Brown and Roose [24] on anxiety in patients diagnosed with cancer and the general public found that women and younger people experienced more stress than men and older individuals. Our results are consistent with these studies, indicating that younger or female patients require careful psychological support before undergoing RT.

The stress score used in this study was calculated using an algorithm built into the Galaxy Watch. Although there is no stress standard to which stress scores can be compared, the results of HRV analysis between smartwatches and biological signal sensors appear similar [25]. Therefore, the Galaxy Watch stress score can be used to assess stress. However, it is difficult to combine them with other smartwatches. HR, which can be measured using most smartwatches, showed a significant difference in all groups (Table 2). In addition, daily changes in HRtb according to treatment days were confirmed in 17 patients whose data were obtained over 3 days (Fig. 2). HRtb decreased as treatment progressed, particularly on day 3, suggesting that patient stress levels were high on the first and second days of RT, but returned to normal by the third day.

Although our study demonstrated an increase in anxiety in 29 patients receiving RT, it is essential to consider that RT and chemotherapy are sometimes administered concurrently, and that chemotherapy can affect a patient's biological signals even if administered before. We chose to use a smartwatch in this study because it is easy for patients to wear. However, the time resolution of the smartwatch data was in minutes, and the data were averaged per minute. A device with better time resolution may provide a more precise anxiety analysis.

In conclusion, our study demonstrated that patients experience psychological anxiety during RT, based on a quantitative analysis of their biological signals. Further research is needed to develop strategies to reduce patient anxiety before RT.

Statement of Ethics

This study was approved by the Institutional Review of Samsung Medical Center (IRB No. 2020-11-162). Written consent was obtained from participants to participate in this study.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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Author Contributions

Conceptualization, YH; Investigation, SWJ, CIJ, DYL; Formal analysis, SWJ; Writing of the original draft, SWJ; Writing of the review and editing, HP, WP, YH.

Data Availability Statement

The data supporting this study's findings are available from the corresponding author upon reasonable request.

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