



OPEN Longitudinal assessment of tricuspid regurgitation following conduction system pacing

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Tricuspid regurgitation (TR) is a well-known complication of pacemaker implantation (PMI). Recently, the conduction system pacing (CSP) technique, which could avoid the development of ventricular dyssynchrony, was established. However, the impact of CSP on TR is unclear. This study aimed to describe the association between CSP and worsening TR. The data of 110 patients who were given a transthoracic echocardiogram (TTE) before and after PMI were retrospectively analyzed. The severity of TR was classified into four groups. Worsening TR was defined as one or more grade increases in TR. Twenty (18.2%) patients had worsening TR, and 7 patients (6.4%) had TR \geq moderate after PMI. After comparing the patients with and without CSP, 5 (27.8%) and 15 (16.3%) patients, respectively, had worsening TR, but the frequency did not indicate a significant difference ($P=0.25$). The frequency of TR \geq moderate after PMI in the former group was significantly higher than in the latter group at 3 (16.7%) and 4 (4.3%), respectively ($P=0.05$). This study revealed that patients with CSP had a higher frequency of TR \geq moderate after PMI compared to patients without CSP in the medium term.

Keywords Tricuspid regurgitation, Cardiac physiologic pacing, Conduction system pacing, Pacemaker

Tricuspid regurgitation (TR) is a well-known complication in patients with cardiac implantable electronic devices (CIED), such as pacemakers (PMs), implantable cardioverter defibrillators (ICDs), and cardiac resynchronization therapy (CRT) devices. Previous studies have reported an association between the insertion of right ventricular (RV) leads and worsening TR¹. Kim et al.² indicated that TR worsened after RV lead implantation, and patients with an ICD had a higher rate of TR worsening compared to patients with PM. Arabi et al.³ concluded that RV lead implantation was associated with worsening TR.

Several mechanisms of worsening TR have been suggested. One study showed that RV leads could result in the malfunction of the tricuspid valve (TV) due to crossing TV, and some lead characteristics, such as diameter or elasticity, were associated with the development of TR². Arabi et al.³ also reported that TR was independent of the characteristics of leads, including their diameter or elasticity, among PMs, ICDs, and CRT devices. In addition, RV apical pacing causes electrical dyssynchrony⁴, and it is believed to cause RV lead-induced TR⁴⁻⁶.

Conduction system pacing (CSP) was established to avoid worsening RV dyssynchrony with physiological pacing and to alleviate the detrimental effects of RV apical pacing. Based on this novel procedure, RV dyssynchrony could be ameliorated; however, knowledge of the precise impact of RV lead-induced TR in this setting is limited. The aim of this study was to describe the association between CSP and TR.

Methods

Data collection and the study population

All data were retrospectively acquired at the University of Tokyo Hospital, Tokyo, Japan, from patients who underwent de novo PM implantation (PMI) between January 2014 and December 2021. This study included 413 patients undergoing PMI. The flow of data collection for the study is shown in Fig. 1.

The inclusion criteria were as follows: (1) age \geq 20 years, (2) de novo PMI, (3) available data from a transthoracic echocardiogram (TTE) prior to PMI (pre-TTE) as a baseline, and (4) available data from TTE after PMI (post-TTE). The exclusion criteria were as follows: (1) implantation of a prior CIED, (2) lack of pre-

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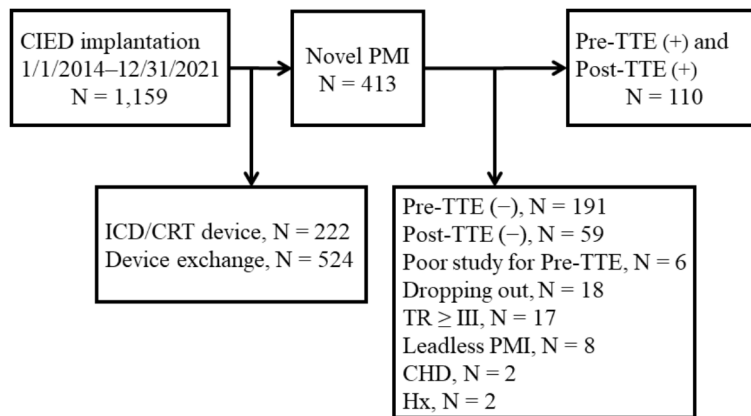


Fig. 1. Flowchart of data collection for the study population. Patients who underwent de novo pacemaker implantation were studied between January 2014 and December 2021. Of these patients, 110 who matched the criteria were enrolled. CHD, congenital heart diseases; CIED, cardiac implantable electronic device; CRT, cardiac resynchronization therapy; Hx, heart transplantation; ICD, implantable cardioverter defibrillator; PM, pacemaker; PMI, pacemaker implantation; Pre-TTE, transthoracic echocardiogram prior to pacemaker implantation; Post-TTE, transthoracic echocardiogram after pacemaker implantation; TR, tricuspid valve regurgitation.

TTE data, (3) lack of post-TTE data, (4) dropping out of follow-up, (5) TR \geq moderate, (6) leadless PMI, (7) congenital heart diseases, and (8) heart transplantation.

Measurement of cardiac functions

In this study, we evaluated the severity of TR based on the jet area observed in Doppler TTE TR grades with TTE (Vivid E95; GE Healthcare or EPIQ7; Philips Healthcare) according to recommendations from the American Society of Echocardiography⁷. TR severity was classified into four groups: none or trivial, mild, moderate, or severe. Worsening TR was defined as one or more grade increases in TR. Pre-TTE and post-TTE data were collected within 6 months prior to PMI and at least 12 months after PMI, respectively. Although evaluating TR severity using jet area is considered a qualitative measure, it is widely accepted and established in clinical practice. To minimize inter-rater variability in this study, all data were reviewed by cardiovascular experts.

Definition of clinical variables

Atrial fibrillation (AF) was diagnosed using an electrocardiogram, and ischemic heart disease (IHD) was diagnosed by angiography or scintigraphy, and pulmonary hypertension (PH) was diagnosed through right heart catheterization.

Strategy for lead tip placement

During the study period, all PMIs were performed by four physicians who belonged to our hospital. The algorithm for RV lead tip placement was as follows: Before 2017, two physicians aimed to achieve nonselective His bundle pacing (NS-HBP). If it failed, there was an attempt to place the RV lead tips in the septum. If septal placement was not suitable because of its threshold, it was placed in the apex as the last resort. The other two physicians aimed to place it in the septum first. If it was not suitable because of its threshold, it was placed in the apex instead of the septum (Fig. 2). In 2017 or later, two physicians aimed to achieve NS-HBP. If it failed, they changed the procedure from NS-HBP to left bundle branch area pacing (LBBAP). The other two physicians aimed to place it in the septum first. If it was not suitable because of its threshold, it was placed in the apex instead of the septum (Fig. 3). CSP was defined as LBBAP or HBP, which was determined according to the PMI procedure records. In CSP patients, RV leads were placed with 3830 leads (Medtronic, Inc., Minneapolis, MN, USA).

Statistical analysis

The patients were divided into 2 groups: CSP and non-CSP. The differences in baseline characteristics were compared between the 2 groups. In the case of non-corresponding data, categorical variables were expressed as N (%) and subjected to the chi-square test or Fisher's exact test, as appropriate. Continuous variables were expressed as mean \pm standard deviation or median (interquartile range) and subjected to the Student's *t*-test or Wilcoxon rank-sum test, as appropriate. In the case of the corresponding data, categorical variables were denoted by N (%), and the Wilcoxon rank-sum test was performed, as appropriate. All statistical analyses were performed using IBM SPSS version 28.0.0.0 (IBM Corp., Armonk, NY, USA), and a two-tailed *P* value \leq 0.05 indicated statistical significance.

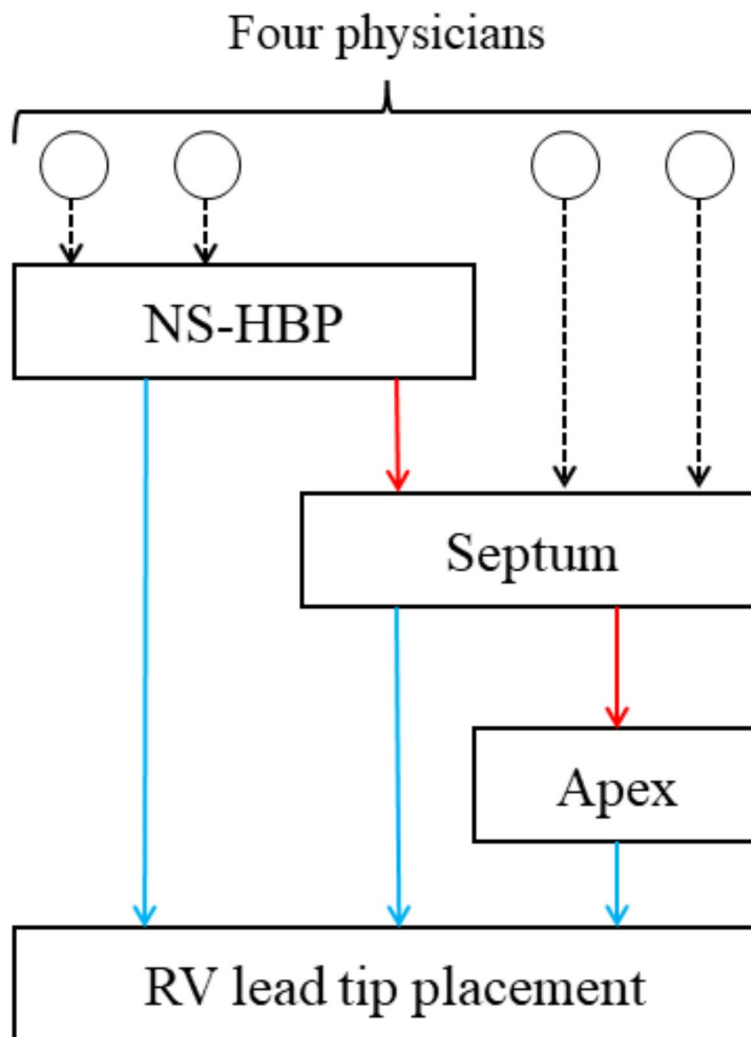


Fig. 2. Flowchart of right ventricular lead tip placement before 2017. Before 2017, two physicians aimed to achieve nonselective His bundle pacing or placement in the septum or apex. The other two physicians aimed to place it in the septum or apex. The blue and red arrows indicate success and failure, respectively. NS-HBP, nonselective His bundle pacing; RV, right ventricle.

Ethical approval

The institutional ethical committee, Research Ethics Committee of the Faculty of Medicine of the University of Tokyo, approved this study at the University of Tokyo (No. 2650-(13)). The requirement for written informed consent was waived by the institutional ethical committee for the retrospective cohort. The study protocol complied with the Declaration of Helsinki.

Results

Patient background

We enrolled 110 patients who underwent de novo PMI and had pre-TTE and post-TTE data. All patients underwent dual-chamber PMI. The mean age was 70.7 ± 12.7 years, and 61 (55.5%) patients were male. RV lead tips were placed as follows: 10 (9.1%) in the RV apex, 82 (74.5%) in the RV septum, 9 (8.2%) in the LBBAP, and 9 (8.2%) in the HBP. In total, 18 (16.4%) patients had CSP. There was no significant difference in background between patients with and without CSP (Table 1). Additionally, none of the study participants had a history of PH. Throughout the observational period, no patients developed heart failure (HF).

Severity of tricuspid regurgitation through pacemaker implantation

For all patients, the median days of pre-TTE and post-TTE data obtained were 2.5 months before PMI and 21.0 months after PMI. TR severity of the patients on the pre-TTE was distributed as 63 (57.3%) were trivial or less and 47 (42.7%) were mild, while for post-TTE, 68 (61.8%) were trivial or less, 35 (31.8%) were mild, and 7 (6.4%) were moderate or more. There were 20 (18.2%) patients with worsening TR. The difference in the TR distributions between pre- and post-TR ($P=0.46$) was not significant (Table S1, Fig. S1).

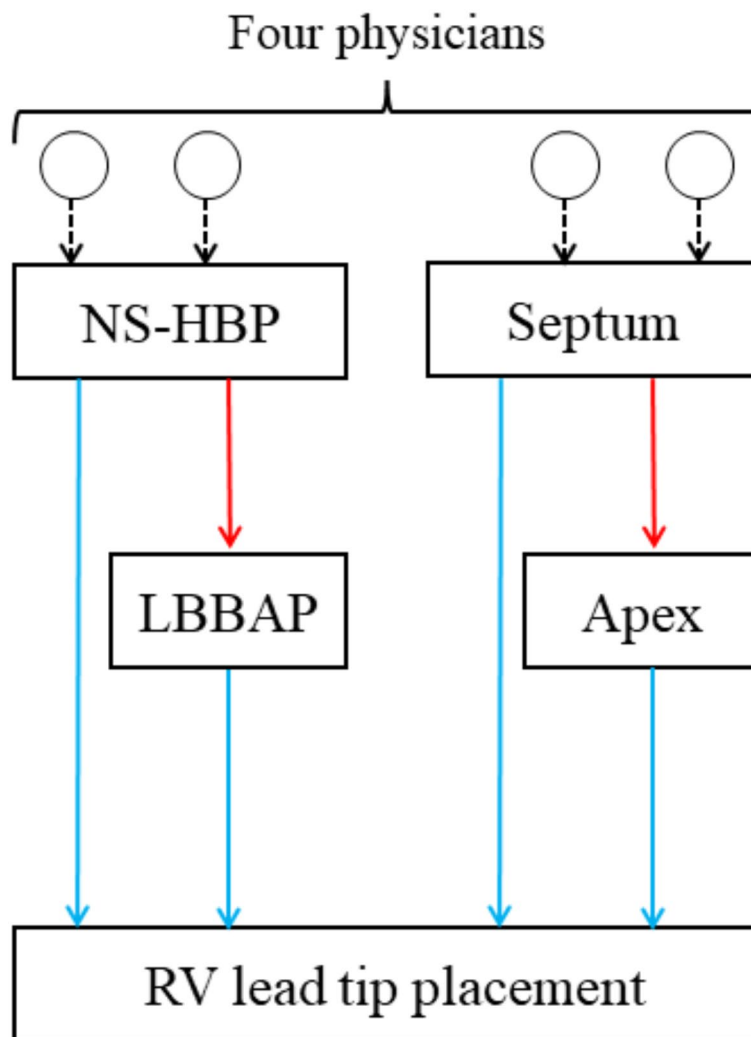


Fig. 3. Flowchart of right ventricular lead tip placement in 2017 or later. In 2017 or later, two physicians aimed to achieve non-selective His bundle pacing or left bundle branch area pacing or placement in the septum or apex. The blue and red arrows indicate success and failure, respectively. NS-HBP, nonselective His bundle pacing; LBBAP, left bundle branch area pacing; RV, right ventricle.

Characteristic	Total (N = 110)	CSP (N = 18)	Non-CSP (N = 92)	P value
Demographic				
Age, (years)	70.7 ± 12.7	73.6 ± 8.9	70.1 ± 13.2	0.29
Male, N (%)	61 (55.5)	10 (55.6)	51 (55.4)	1.00
Medical history AVB, N (%)	63 (57.3)	13 (72.2)	50 (54.3)	0.20
IHD, N (%)	34 (30.9)	5 (27.8)	29 (31.5)	1.00
AF, N (%)	40 (30.9)	5 (27.8)	35 (38.0)	0.59
Pacing frequency				
Ap, (%)	29.0 (6.0–77.9)	23.8 (3.3–50.5)	30.5 (8.3–81.8)	0.25
Vp, (%)	51.4 (1.0–99.9)	98.9 (7.0–100.0)	21.5 (1.0–99.8)	0.11

Table 1. Patients' background. CSP, conduction system pacing; AVB, atrioventricular block; IHD, ischemic heart disease; AF, atrial fibrillation; Ap, atrial pacing; Vp, ventricular pacing.

In patients with CSP (N = 18), TR severity on the pre-TTE was distributed as 10 (55.6%) were trivial or less and 8 (44.4%) were mild, while for post-TTE, 8 (44.4%) were trivial or less, 7 (38.9%) were mild, and 3 (16.7%) were moderate or more. There were 5 (27.8%) patients with worsening TR. The difference in the TR distributions between pre- and post-TR ($P = 0.10$) was not significant (Table S2, Fig. S2). For patients without CSP (N = 92),

Characteristic	Total (N = 110)	CSP (N = 18)	Non-CSP (N = 92)	P value
TR > Moderate, N (%)	7 (6.4)	3 (16.7)	4 (4.3)	0.05
Worsening TR, N (%)	20 (18.2)	5 (27.8)	15 (16.3)	0.25

Table 2. Tricuspid regurgitation with and without conduction system pacing. CSP, conduction system pacing; TR, tricuspid regurgitation.

TR severity in pre-TTE was distributed as 53 (57.7%) were trivial or less and 39 (42.4%) were mild, while for post-TTE, 60 (65.2%) were trivial or less, 28 (30.4%) were mild, and 4 (4.4%) were moderate or more. There were 15 (16.3%) patients with worsening TR. The difference in the TR distributions between pre- and post-TR ($P=0.98$) was not significant (Table S3, Fig. S3).

In patients with septal placement ($N=82$), the severity of TR in pre-TTE was distributed as 48 (56.6%) were trivial and 34 (41.5%) were mild, while for post-TTE, 52 (63.5%) were trivial or less, 27 (32.9%) were mild, and 3 (3.7%) were moderate or more. There were 13 (15.9%) patients with worsening TR. The difference in the TR distributions between pre- and post-TR ($P=0.99$) was not significant (Table S4, Fig. S4).

In patients with LBBAP ($N=9$), the severity of TR in pre-TTE was distributed as 4 (44.4%) were trivial or less and 5 (55.6%) were mild, while for post-TTE, 4 (44.4%) were trivial or less, 3 (33.3%) were mild, and 2 (22.2%) were moderate or more. There were 2 (22.2%) patients with worsening TR. The difference in the TR distributions between pre- and post-TR ($P=0.41$) was not significant (Table S5).

In patients with HBP ($N=9$), the severity of TR in pre-TTE was distributed as 6 (66.7%) were trivial or less and 3 (33.3%) were mild, while for post-TTE, 4 (44.4%) were trivial or less, 4 (44.4%) were mild, and 1 (11.1%) was moderate or more. There were 3 (33.3%) patients with worsening TR. The difference in the TR distributions between pre- and post-TR ($P=0.08$) was not significant (Table S6).

Comparison of tricuspid regurgitation among various pacing sites

Among all the patients, 7 (6.4%) had TR \geq moderate after PMI, and 20 (18.2%) had worsening TR. For patients with and without CSP, the frequency of TR \geq moderate after PMI in the former group was significantly higher than in the latter group: 16.7% ($N=3$) versus 4.3% ($N=4$), respectively ($P=0.05$). However, for worsening TR, there were 5 (27.8%) and 15 (16.3%) patients, respectively, which did not indicate a significant difference ($P=0.25$) (Table 2).

When comparing patients with RV septal pacing and those with LBBAP, for TR \geq moderate after PMI, there were 3 (3.7%) and 2 (22.2%) patients, respectively. There was no statistically significant difference between the groups ($P=0.20$). For worsening TR, there were 13 (15.9%) and 2 (22.2%) patients, respectively. There was no statistically significant difference between the groups ($P=0.63$) (Table S7).

When comparing patients with LBBAP and HBP, for TR \geq moderate after PMI, there were 2 (22.2%) patients and 1 (11.1%) patient, respectively. There was no statistically significant difference between the groups ($P=0.53$). For worsening TR, there were 2 (22.2%) and 3 (33.3%) patients, respectively. There was no statistically significant difference between the groups ($P=0.60$) (Table S8).

Discussion

The current study indicated that patients with CSP had a higher frequency of TR \geq moderate compared to patients without CSP. This finding is consistent with a previous study⁸. It is believed that 3830 leads enable us to attain CSP more easily, including LBBAP or HBP. The 3830 leads have a smaller diameter, and one might assume they would not typically affect TV closure⁹. However, this is not necessarily the case. Since the left bundle branch (LBB) and His bundle are located near the TV, the lead tip could potentially interfere with the movement of the TV, indicating a more complex issue.

Although the etiology of TR is complex, certain factors—such as IHD, AF, and PH—are widely recognized in daily clinical practice as significant contributors to its development. Regarding patient backgrounds, we found no significant differences in the prevalence of IHD or AF between patients with and without CSP, and none of the patients had a history of PH. Furthermore, based on patients' electronic records, we confirmed that none of the participants developed heart failure during the study. Thus, we believe that the observed worsening or new-onset TR in this study is likely attributable to PMI, based on these findings.

Several mechanisms have been proposed to explain how CSP may induce TR. Although CSP, such as LBBAP and NS-HBP, could be expected to improve RV dyssynchrony, it seems that the approach to stimulating the intra-RV is different. The former technique aims to stimulate LBB, while the latter stimulates the His bundle, which is located superior to the LBB. Therefore, HBP seemed much similar to physiological pacing. One of the assumed mechanisms of worsening TR in patients with LBBAP is that the papillary muscles in the RV do not contract synchronously with intra-RV stimulation. An interesting finding was that the frequency of ventricular pacing (Vp) was higher in patients with CSP compared to those without CSP, although this difference was not statistically significant. In contrast, Li et al.⁸ reported that a high Vp percentage was not a risk factor for TR progression in patients with LBBAP. In our study, CSP included both LBBAP and NS-HBP, and the relatively small sample size limited our ability to assess each group individually. Although statistical significance was not observed, our findings could support the hypothesis that higher Vp frequency may contribute to TR progression.

Right bundle branch block (RBBB) is a major conduction system disorder, and RV stimulation in patients with RBBB propagates a resemblance to that in patients with LBBAP. An association between these disorders has not been reported, nevertheless it is known that TR often coexists with RBBB. Although another previous study

reported that HBP had less TR severity than LBBAP⁸, the current study did not indicate any difference between these groups in terms of TR severity. Therefore, further studies are needed to confirm these findings.

Finally, a systematic review and meta-analysis of six independent studies^{10–15} did not report any statistically significant association between CSP and TR¹⁶. However, the review noted substantial heterogeneity, as each study focused exclusively on either LBBAP or HBP rather than a combined CSP group. Our study's finding of potential TR worsening with CSP is notable and may contribute to a more comprehensive understanding of CSP-induced TR. In our CSP group, consisting of both LBBAP and NS-HBP, comparisons showed no statistically significant differences. While TR associated with LBBAP and HBP has been discussed in previous studies, results remain inconclusive. For example, one study found no worsening of TR with LBBAP compared to conventional RV pacing¹⁷, while another reported an increased TR risk with LBBAP⁸. In addition, another systematic review¹⁸ on TR and HBP indicated that, while four studies reported TR improvement from baseline^{10,19–21}, three found TR deterioration^{22–24}.

Despite the relatively small sample size in our study, the differences observed in TR outcomes between LBBAP and HBP groups suggest that these subgroups may have distinct characteristics, warranting separate analyses. Although our study did not focus on clinical outcomes such as HF and mortality, prior research has shown that PMI-induced TR is independently associated with poor prognosis¹⁶. Therefore, our finding of increased TR frequency post-PMI is concerning. These fundamental issues may stem from the retrospective nature of our study design. Given the uncertain benefit of CSP for TR, prospective cohort studies examining both combined CSP and specific LBBAP and HBP groups are essential to address these issues. Closer follow-up is also warranted to detect any potential TR progression.

Limitations

Our study has some limitations. This study was conducted retrospectively in a single center. There was a relatively small number of participants; therefore, further studies are needed to confirm our findings. Additionally, 200 patients were excluded due to missing or poor TTE data. Given the retrospective design of this study, establishing a definitive cause-and-effect relationship was challenging, even though we confirmed that none of the study participants developed identifiable clinical events contributing to TR, aside from PMI, based on their electronic records. To minimize the risk of missing TTE data and thoroughly exclude other potential causes of TR, a prospective cohort study would be preferable. Finally, although previous studies reported that perforation and/or laceration of the TV were also regarded as RV lead-induced TR mechanisms^{25–27}, the histological findings on the TV were not examined in our study.

Conclusion

Patients with CSP had a higher frequency of TR \geq moderate in the medium term. Further studies are needed to investigate whether LBBAP has a worse impact on TR severity.

Data availability

The data that support the findings of this study are available on request from the corresponding author, K.F. The data are not publicly available due to restrictions in the ethical approval.

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Author contributions

M.O. contributed to the study's design, data collection/analysis/interpretation, and manuscript writing. K.F., E.H., T.O., K.K., K.G., M.H., T.K., Y.S., K. Y., G.O., I.K. contributed to data collection/interpretation/management and writing of the manuscript. K.F. was the senior supervisor of the study. All authors take responsibility for all aspects of the reliability and freedom from bias of the data presented and their discussed interpretations.

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Declarations

Competing interests

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Additional information

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