Do we need to rethink the determination of exercise-related energy expenditure in cardiac telerehabilitation interventions?

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Do we need to rethink the determination of exercise-related energy expenditure in cardiac telerehabilitation interventions?

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GQ1

GQ2 **Abstract**

GQ4 GQ5 The American College of Sports Medicine determined the energy consumption of daily activities and sports. Cardiac telerehabilitation (CTR) requires knowing how much energy people consume in daily life outside of cardiac rehabilitation activities. Therefore, we have investigated if the estimated values are valid in CTR. Data from two studies were incorporated. The first study measured ventilatory threshold (VT)1, VT2, and peak exercise on cardiopulmonary exercise testing (CPET) collected from 272 cardiac (risk) patients and compared them to the estimated oxygen consumption (VO_2) at low-to-moderate-intense exercise (3–6 metabolic equivalents [METs]). Next, a patient-tailored application was developed to support CTR using these estimated values, and the intervention (the second study) was conducted with 24 coronary artery disease patients using this application during a CTR intervention. In the first study, VO_2 at VT1, VT2 and peak exercise corresponded to 3.2 [2.8, 3.8], 4.3 [3.8, 5.3], and 5.4 [4.5, 6.2] METs, which are significantly different from the estimated VO_2 at low-to-moderate-intense exercise, especially lower in older, obese, female, and post-myocardial infarction/heart failure patients. These VO_2 varied considerably between patients. The telerehabilitation study did not show significant progress in peak VO_2, but using the application's estimated target, 97.2% of the patients achieved their weekly target, which is a significant overestimate. The estimated and observed exercise-related energy expenditures by CPET were significantly different, resulting in an overestimation of the exercise done by the patients at home. The results can have a significant impact on the quantification of exercise dose during (tele)rehabilitation programs.

Keywords
Digital health, mobile health, smartphone application, oxygen consumption, physical activity, cardiac telerehabilitation

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Introduction

Exercise-based rehabilitation is important to reduce cardiovascular and total mortality and/or re-hospitalization risk in patients with heart disease.[1] The key driver in this adverse event reduction is the volume of exercise.[2] The European Society of Cardiology/European Association of Preventive Cardiology guideline recommends that adults engage in at least 150 minutes of moderate-intensity exercise or 75 minutes of vigorous-intensity exercise, or a combination of both, per week.[1] Hence, achieving the proper exercise volume, and being able to properly monitor the volume of exercise/oxygen consumption (VO_2), is important.

In recent years, the importance of cardiac telerehabilitation (CTR) has been recognized and accelerated by the COVID-19 pandemic.[3,4] Cardiac rehabilitation (CR)

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programs have been postponed or cancelled, and CR is not financially sustainable in many locations during the pandemic.[5] In addition, pre-existing CVD was associated with worse prognosis and increased risk of death in patients with COVID-19.[6] In this context, several trials of CTR interventions have been conducted.[7–9] CTR includes unsupervised CR activities outside the hospital. Since CTR requires knowing how much energy people consume in their daily lives outside of traditional CR activities in a hospital, it is necessary to estimate the actual VO_2 value in order to follow-up CTR patients.

Table 1. The use flow of the HeartHab application.

	Procedures in the application	Examples
#1	The parameters of a physiotherapist's exercise prescription (minimum and maximum frequency, session duration, and targets of exercise [represented by the "scores" written above]) are recorded in the application in advance.	The minimum and maximum frequency are 3 and 5 days per week. The minimum and maximum session durations are 20 and 45 minutes. The minimum and maximum targets of exercise are 360 and 2030.
#2	A patient enters specific PA data into the application as an activity log.	A patient enters "30 minutes of walking" into the application.
#3	Specific PA data entered into the application by a patient is converted into weighted calculated exercise volume with energy requirements (using estimated VO_2) for each type of activity[7].	VO_2 for walking is 4 METs.
#4	The "score" for each individual was calculated using the following formula: "score" = duration of an activity (min) * ((VO_2 of an activity * resting VO_2 * body weight)/200)[18].	For a body weight of 90 kg, "score" = 30 (min) * 4 (mL/min*kg) * 3.5 (mL/min*kg) * 90 (kg)/200 = 189
#5	The actual load of daily activities per week calculated using the estimated VO_2 (the weekly total in #4) is compared with the minimum and maximum target values for exercise written above.	The total "score" for the week is 4060. This score exceeds the minimum (360) and maximum (2030) targets of exercise.
#6	The Number Of Weeks Over The Period When Targets Are Achieved Is Calculated (If The "Score" Exceeds The Minimum Targets Of Exercise, The Weekly Goal Is "Achieved").	Because The Goal (Weekly "Score" To Reach) Is Achieved In 6 Weeks Of The Intervention Period (8 Weeks), This Results In The Achievement Rate Of 75% (6/8).

PA, physical activities; VO_2, oxygen consumption; METs, metabolic equivalents.

For decades, the American College of Sports Medicine (ACSM) estimated VO_2 of daily activities and sports[10,11] has been used as the amount of oxygen consumption for exercise prescription. In the list of the ACSM, VO_2 is expressed as metabolic equivalents (METs) using the standard definition of one MET (=3.5 mL/kg/min). One MET is a basic unit, meaning the VO_2 in the resting sitting position. However, recent studies question the estimated VO_2 value by ACSM to quantify the volume of exercise, at least in healthy individuals.[12] Another study suggested that the actual VO_2 of physical activities (PA) measured with a portable indirect calorimetry differ significantly from estimated value.[13] In addition, it has recently been reported that the resting energy expenditure actually is overestimated in older adults.[14] A recent systematic review[15] showed that resting metabolic rate values are lower than the conventional 3.5 mL/kg/min in adults over 60 years of age. Thus, it follows that the use of estimated VO_2 for the dosing of exercise and PA may be inappropriate.

The appropriateness of the use of the estimated values of VO_2 in patients with heart disease has not been studied in detail, nor has its impact on the monitoring of rehabilitation programs (e.g. by smartphone applications during telerehabilitation) been examined.

Therefore, we aimed to study (1) the detailed VO_2 values during CR in patients with heart disease obtained by cardiopulmonary exercise testing (CPET) and (2) the clinical influence of estimated vs. observed VO_2 during CTR with smartphone monitoring.

Methods

This paper built further on data from two recent studies. The inclusion and exclusion criteria, and the procedures were described in the articles[16,17] about these studies in detail. Briefly, in the first study[16] (Study 1) CPET data were prospectively collected from 272 heart disease (risk) patients at entry of their CR program (at Jessa Hospital, Hasselt, Belgium). To assess the value of the VO_2 in this cohort study, the exact VO_2 at ventilatory threshold (VT)1, VT2, and peak exercise were measured by CPET.

In the second study (Study 2), the HeartHab application was developed (by Hasselt University), which is a comprehensive patient-tailored application to support CTR, and used by patients (at Jessa Hospital, Hasselt, Belgium) with coronary artery disease (CAD) in a CTR intervention. This was a prospective, randomized, open-label, crossover study of two different methods of CR for CAD patients. After obtaining informed consent, the patients were randomly assigned to either the 'application first' group (using the HeartHab application in the first 2 months and receiving usual care in the next 2 months) or the 'usual care first' group (receiving usual care in the first 2 months and using the HeartHab application in the next 2 months). The application covered several factors related to CR including PA and exercise training, and presented tailored PA targets (minimum and maximum exercise goals) to the patients.[18] With respect to PA (type of exercise [and its VO_2] and duration of exercise), datasets for 24 out of 32 participating patients in Study 2 were completed and used in the current study. The specific PA data of each session (e.g. jogging, walking, housework), which the patient entered into the application as an activity log, was translated into the volume of exercise calculated by weighting the energy requirements (represented by the VO_2) of each type of activity.[19] Then the "score" per individual were calculated with the formula: "score" = duration of an activity (min) * ((VO_2 of an activity * resting VO_2 * body weight) /200).[20] The type of activities was divided into two categories: "cardio" activities, which is structured and planned exercise of moderate or greater intensity[21] (e.g. jogging, walking), and "non-cardio" activities, which is anything else (e.g. gardening, fishing). The HeartHab application recorded the parameters of the exercise prescription (minimum and maximum frequency, session duration, and minimum and maximum targets of exercise (represented by the "score" written above)) and the actual load of daily activities per week calculated using the estimated VO_2. Physiotherapists prescribed the personalized target range of the exercise using the caregivers' dashboard application. The application integrated the European Association of Preventive Cardiology-supported EXPERT tool for exercise recommendations.[18] Finally, the number of weeks over the period when targets are achieved is calculated (if the "score" exceeds the minimum targets of exercise, the goal is "achieved"). The use flow of the HeartHab application is summarized in Table 1, along with examples. During the study period, the International Physical Activity Questionnaire[22] and the CPET were performed at baseline, the crossover point (month 2), and the end of the study (month 4).

Outcomes

The primary outcome was the number of weeks over the period when targets of every patient are achieved during 2 months of the application intervention phase in Study 2. This data was calculated based on the results obtained in Study 2.

In terms of the secondary outcomes, we measured the actually achieved VO_2 at VT1, VT2 and peak exercise for each patient in both studies. These values were calculated using CPET data at baseline. These values were compared with the estimated VO_2 (from the Compendium of PA),[10,11] in which three and six METs are used as the borderlines between light-to-moderate and moderate-to-vigorous intensity exercises.[19] In addition, to see the effect of exercise capacity on VO_2, the relationship between VO_2 at VT1 or VT2 and the % peak VO_2 (predicted) was examined in Study 1. The % peak VO_2 (predicted), which reflects exercise capacity, was calculated by dividing the peak VO_2 by the predicted peak VO_2. The predicted peak VO_2 was calculated using the equation.[23] Finally, the dataset from both studies was used to detect predictors of deviation of observed VO_2 at VT1 and VT2 from estimated values, which were called as "delta VT1" (observed VO_2 at VT1 – 3 [METs]) and "delta VT2" (observed VO_2 at VT2 – 6 [METs]).

Statistical analysis

All statistical analyses were carried out with SPSS for Windows version 27.0 (SPSS Inc., Chicago, IL). Data were shown as mean (± standard deviation) (for parametric data), as median [25th, 75th percentile] (for non-parametric data), or as percentages (for nominal data). The chi-square test was carried out to calculate within-group proportions. As parametric and non-parametric tests, the paired t test and Wilcoxon's signed-rank test were used to compare parameters in the same population. Stepwise multiple linear regression analysis was performed to determine the predictors written above. A two-tailed P-value < 0.05 was considered statistically significant.

Results

Table 2 shows the baseline characteristics for the 272 patients in Study 1 and 24 patients in Study 2. Due to differences in inclusion criteria, Study 2 had more cases of acute myocardial infarction (MKI) and coronary treatment than Study 1. More patients in Study 1 took beta blockers and angiotensin converting enzyme inhibitors/angiotensin II receptor blockers than in Study 2, and median peak VO_2 in Study 1 was lower than in Study 2, which might be due to different proportions of heart failure (HF).

Figure 1 shows the measured VO_2 at different stages of the exercise. VO_2 at VT1 corresponded 3.2 [2.8, 3.8] METs, VO_2 at VT2 corresponded 4.3 [3.8, 5.3] METs, and VO_2 at peak exercise corresponded to 5.4 [4.5, 6.2] METs for the patients in Study 1, showing considerable variation between patients. Figure 2 also demonstrates significant correlations between the % peak VO_2 (predicted) and the VO_2 at VT1 ($r = 0.419$, $P < 0.001$), and the VO_2 at VT2 ($r = 0.546$, $P < 0.001$) in Study 1 patients.

Table 3 outlines the weekly "scores" during intervention from estimated values (the compendium) and the number of weeks over the period when targets are achieved considering all and "cardio" activities only. 97.2% (= 52.6% + 44.6%) of the patients reached the minimal exercise target for all activities. If limited to only "cardio" activities, 85.2% (= 32.6% + 52.6%) of the patients reached the minimal exercise target.

Lastly, stepwise multiple linear regression analysis was performed and the results of the model with the highest

Table 2. Baseline characteristics in Study 1 and Study 2.

Patients		Study 1 ($n =$ 272)	Study 2 ($n = 24$)[a]
Male, n (%)	196 (72)	20 (83)	
Age	63 ± 11	60 ± 8	
Body mass index (kg/m^2)	26.5 [24.1, 29.7]	28.5 [24.4, 33.7]	
Cardiovascular disease	Suffered from acute myocardial infarction, n (%)	90 (33)	16 (70)
	Revascularized by CABG, n (%)	57 (21)	6 (26)
	Revascularized by PCI, n (%)	161 (59)	21 (91)
	Heart failure, n (%)	35 (13)	1 (4)
	Implantable cardio defibrillator, n (%)	9 (3)	1 (4)
Cardiovascular risk factors	Hypertension, n (%)	141 (52)	10 (43)
	Dyslipidemia, n (%)	186 (68)	15 (65)
	Diabetes mellitus, n (%)	33 (12)	6 (26)
Medications	Beta blockers, n (%)	212 (78)	13 (57)
	Angiotensin converting enzyme inhibitors/angiotensin II receptor blockers, n (%)	132 (49)	18 (78)
	Statins, n (%)	224 (82)	22 (96)
Ergospirometry at baseline	Peak VO_2 (mL/min)	1466 [1197, 1826]	1962 [1778, 2237]

Values are expressed as the mean ± standard deviation, the median [25th, 75th percentile], or number (%).
CABG, coronary artery bypass grafting; PCI, percutaneous coronary intervention; VO_2, oxygen consumption; VT, ventilatory threshold.
[a]Data of one patient was lacking for cardiovascular disease, cardiovascular risk factors, and medications.

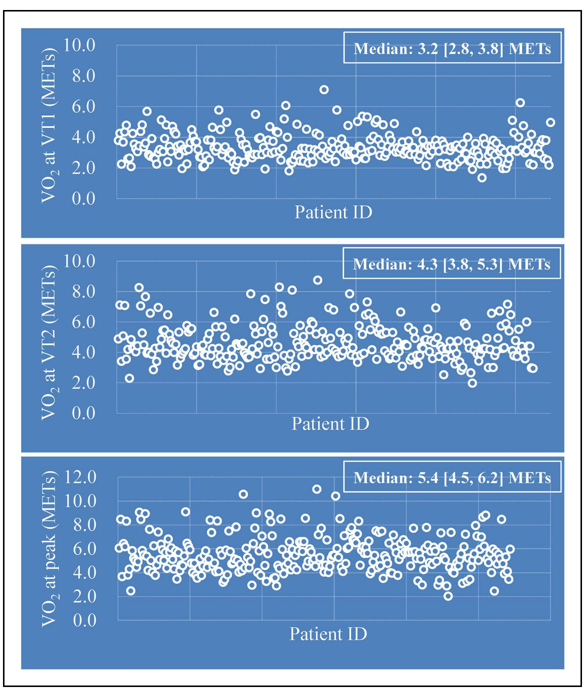

Figure 1. VO_2 at VT1, VT2, and peak exercise derived from a CPET dataset of 272 patients.
VO_2 is expressed as median [25th, 75th percentile].
VT, ventilatory threshold; CPET, cardiopulmonary exercise testing.

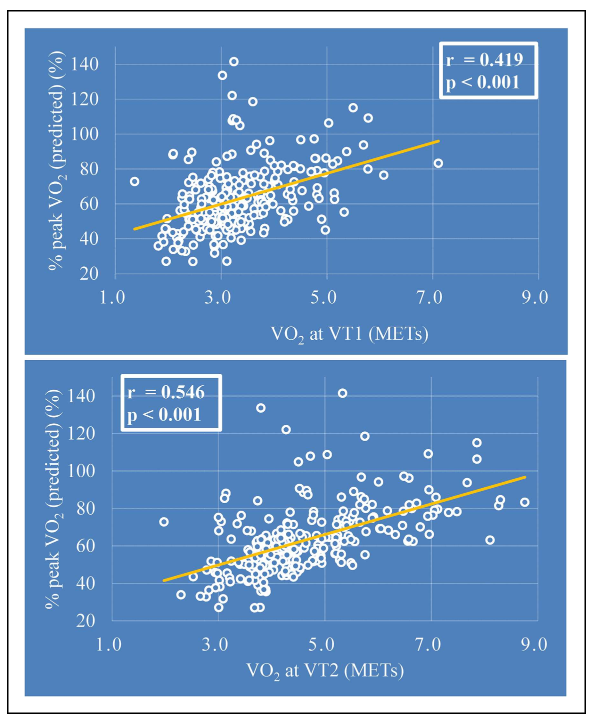

Figure 2. Correlation between % peak VO_2 and VO_2 at VT1 and VT2 from a CPET dataset of 272 patients.
VO_2, oxygen consumption; VT, ventilatory threshold; CPET, cardiopulmonary exercise testing.

coefficient of determination are shown in Table 4. Covariates of age ($P < 0.001$), body mass index (BMI) ($P < 0.001$), and MI ($P = 0.030$) showed a significant negative correlation with delta VT1, while male sex ($P = 0.008$) and percutaneous coronary intervention (PCI) ($P = 0.001$) demonstrated a significant positive correlation with it. Additionally,

Table 3. Overview of the number of weekly "scores" and the number of weeks over the period when targets are achieved in Study 2.

Patients ($n = 24$)		With all activities	With only "cardio" activities
Mean weekly "scores"		3709 [2595, 5980]	2093 [1017, 3475]
Achievement rates of exercise (represented by "scores") target (%)	> max target	52.6 (= 92w/175w)	32.6 (= 57w/175w)
	in zone	44.6 (= 78w/175w)	52.6 (= 92w/175w)
	< min target	2.9 (= 5w/175w)	14.9 (= 26w/175w)

Values are expressed as the median [25th, 75th percentile] or %.
METs, metabolic equivalents.

Table 4. Multiple linear regression analysis for predicting parameters which affect deviation of observed VO_2.

1. Dependent variable: delta VT1		
Variables	$R^2 = 0.248$ ($P < 0.001$)	
	Beta	***P*-Value**
Body mass index	−0.342	<0.001
Age	−0.338	<0.001
Percutaneous coronary intervention	0.187	0.001
Male sex	0.136	0.008
Myocardial infarction	−0.123	0.030
2. Dependent variable: delta VT2		
Variables	$R^2 = 0.259$ ($P < 0.001$)	
	beta	***P*-Value**
Age	−0.325	< 0.001
Body mass index	−0.321	< 0.001
Male sex	0.166	0.002
Percutaneous coronary intervention	0.134	0.016
Heart failure	−0.125	0.025

For sex, male was entered as "1" and female was entered as "0."
VT, ventilatory threshold.
R^2, coefficient of determination; beta, standardized regression coefficients.

covariates of age ($P < 0.001$), BMI ($P < 0.001$), and HF ($P = 0.025$) indicated a significant negative correlation with delta VT2, while male sex ($P = 0.002$) and PCI ($P = 0.016$) showed a significant positive correlation with it.

Discussion

The past meta-analysis[24] has shown that CTR using mobile or web-based platforms improves functional capacity and health-related quality of life. Regarding the safety of CTR, the recent meta-analysis[25] finds no CTR-related deaths or hospitalizations, and no adverse events. The risk of adverse events has been shown to be very low. Therefore, we need to resolve what is needed to implement the CTR intervention.

Our results show that the VO_2 values at VT1 and VT2 (3 and 6 METs) estimated by the ACSM overestimate the real values in cardiac patients, as our results tended to be closer to 3.2 [2.8, 3.8] and 4.3 [3.8, 5.3] METs. This was even more prominent in older, obese, female, and post-MI or HF patients. Using these estimated values of exercise intensity in a smartphone application (e.g. HeartHab application) causes the amount of exercise preformed to be calculated incorrectly. If a cardiac patient reports that he/she "walked at a high intensity," a physician would assume that 6 METs has been achieved, whereas our data show that this is in most patients a more than maximal exercise.

As in the estimated VO_2, 3 and 6 METs are considered as low-to-moderate intense or moderate-to-vigorous intense exercise, the actual VO_2 (at VT1 and VT2) of these patients from the 272-patient dataset was thus overly inconsistent with the estimated VO_2, and these values varied considerably between patients. A recent paper[12] analyzing the CPET of healthy subjects also already pointed out a significant discrepancy between the exercise intensity domains and the fixed METs classification system, leading to the risk for assigning invalid VO_2 to PA and exercise. This logic may thus also apply to cardiac patients. Figure 2 shows a significant relationship between VO_2 at VT1 or VT2 and % predicted peak VO_2. % Predicted peak VO_2 values reflect exercise capacity, so the fitter the cardiac patient, the greater the VO_2 value. This helps to explain the difference between the estimated and actual observed VO_2 of cardiac patients, since heart disease patients are generally exercising intolerant, but their estimated VO_2 is derived from data from physically fit, healthy individuals. In addition, our results from the regression analysis show that the risk of overestimation of the daily activities is greater in subgroups described above. Although the coefficient of determination was not so high, this result also supports the logic.

In Study 2, the difference in observed peak VO_2 by CPET between baseline and month 2 (before crossover) with the HeartHab application and with usual care was not significantly different ($P = 0.226$) (Supplementary Figure S1). Given this result and our usual clinical situation, it is unlikely that 97.2% of the CVD patients achieve their minimum exercise goals. Although it was possible that "non-cardio" activities (such as housekeeping) could have accounted for a large proportion of total activity, even considering only "cardio" activities, Table 3 shows that they are overestimated.

Considering the findings in Study 1, it is thus of no surprise that the calculated "scores" in Study 2 (from estimated VO_2) tended to deviate from the observed VO_2 during baseline CPET. The results suggest that patients with heart disease achieve VT2 or peak exercise at a lower VO_2 than the ACSM-estimated VO_2. The HeartHab application calculates real follow-up data by transforming patient-reported activities in "scores" by using these estimated VO_2 values. This dissociation between the actual VO_2 as they should be for cardiac patients and the estimated VO_2 is one possible cause of the overestimation in the HeartHab application.

Future tasks and research

Mobile health and wearable device interventions are ever more frequently proposed in reviews or implemented in several clinical trials on CR/CTR.[26–29] Several trials of such interventions in CR are ongoing.[30–32] However, to estimate/follow-up the dose of PA and exercise in a valid manner, an appropriate VO_2 calculation algorithm specific to patients with heart disease needs to be established. A new specific parameter would improve this situation, but it is still limited because it is not possible to set VO_2 individually for all types of PA. Rather, it would be better to combine CPET with some objective data (e.g. heart rate (HR) monitoring), since the linear relationship between VO_2 and HR can be used to calculate the absolute value of unique VO_2. A relative measure (e.g. %HRmax), which 2021 ESC guidelines[1] recommended for individualized PA prescription, may be used in future studies.

Study limitations

The results of Study 2 were based on a small number of patients and the baseline CPET data were different from those of Study 1. However, all patients in both studies received the same supervised rehabilitation program and follow-up with CR. In Study 2, the details of the exercises depended on self-reporting of activities by patients, which might cause reporting bias. Finally, patients in both studies did not follow the same CR program, and this difference might have affected the reported PA level results.

Conclusions

The estimated exercise-related energy expenditure is significantly different from observed one in patients with heart disease (risk). This can have a significant impact on the quantification of exercise dose during cardiac (tele) rehabilitation programs. Hence, in patients with heart disease, newly developed and specific exercise-related energy expenditure should be warranted for future studies and clinical applications.

Abbreviations

ACSM	the American College of Sports Medicine
CAD	coronary artery disease
CPET	cardiopulmonary exercise testing
CR	cardiac rehabilitation
CTR	cardiac telerehabilitation
CVD	cardiovascular disease
HR	heart rate
MET	metabolic equivalent
PA	physical activities
VO_2	oxygen consumption
VT	ventilatory threshold

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Authors' contributions

All authors contributed to the conception or design of the work. TK, KC, MS, and DH contributed to the acquisition, analysis or interpretation of the dataset. TK drafted the manuscript. All authors contributed to manuscript revisions. All authors gave final approval and agree to be accountable for all aspects of the work ensuring integrity and accuracy.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. GQ3

Ethics approval and consent to participate

These studies were approved by the ethics committees of Hasselt University and Jessa hospital, Hasselt, Belgium. After careful explanation of these studies to the patients, a signed informed consent was collected.

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Supplemental material

Supplemental material for this article is available online.

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