TEMPUS

Instructions for Use

Tempus ECG-Low EF

Test:
Tempus ECG-Low EF

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INDICATIONS FOR USE

Tempus ECG-Low EF is software intended to analyze resting, non-ambulatory 12-lead ECG recordings and detect signs associated with having a low left ventricular ejection fraction (LVEF less than or equal to 40%). It is for use on clinical diagnostic ECG recordings collected at a healthcare facility from patients 40 years of age or older at risk of heart failure. This population includes but is not limited to patients with atrial fibrillation, aortic stenosis, cardiomyopathy, myocardial infarction, diabetes, hypertension, mitral regurgitation, and ischemic heart disease.

Tempus ECG-Low EF only analyzes ECG data and provides a binary output for interpretation. Tempus ECG-Low EF is not intended to be a stand-alone diagnostic tool for cardiac conditions, should not be used for patient monitoring, and should not be used on ECGs with paced rhythms. Results should be interpreted in conjunction with other diagnostic information, including the patient's original ECG recordings and other tests, as well as the patient's symptoms and clinical history.

A positive result may suggest the need for further clinical evaluation in order to establish a diagnosis of low LVEF. Patients receiving a negative result should continue to be evaluated in accordance with current medical practice standards using all available clinical information.

GENERAL WARNINGS AND PRECAUTIONS

- **Tempus ECG-Low EF has not been evaluated in and should not be used for patients younger than 40 years of age.**
- **Tempus ECG-Low EF is not intended to replace other diagnostic tests.**
- **Results do not represent a diagnosis of low LVEF.**
- **Results do not rule-out low LVEF.**
- **Tempus ECG-Low EF should not be used on ECG recordings with paced rhythms.**
- **Tempus ECG-Low EF should not be used for patient monitoring.**
- **Tempus ECG-Low EF should not be used to initiate any therapy or treatment for low LVEF.**
- **Tempus ECG-Low EF should not be used for repeated testing of the same patient within a 12 month period.**

INTERPRETATION OF RESULTS

RESULT: LOW LVEF DETECTED

Interpretation

This result indicates the device detected signs associated with low left ventricular ejection fraction (LVEF less than or equal to 40%) in the analyzed ECG tracing.

This result does not represent a diagnosis of low LVEF.

Next Steps

In combination with other clinical information, consider further diagnostic evaluation to determine if low LVEF is present.

Do not initiate any treatments based solely on this result.

RESULT: LOW LVEF NOT DETECTED

Interpretation

This result indicates the device did not detect signs associated with low left ventricular ejection fraction (LVEF less than or equal to 40%) in the analyzed ECG tracing.

This result does not rule out current or future low LVEF.

Next Steps

Continue to evaluate for low LVEF in accordance with current medical practice standards.

RESULT: UNCLASSIFIABLE

Interpretation

This result indicates a technical error. The provided ECG tracing could not be analyzed due to characteristics of the ECG tracing and/or associated patient data.

Next Steps

Submit a new ECG that meets input criteria for ECG-Low EF evaluation.

If a new ECG cannot be provided or input criteria cannot be met, continue to evaluate for low LVEF in accordance with current medical practice standards.

FOLLOW-UP

Low LVEF Detected Result

Clinicians should consider the following for patients receiving a "Low LVEF Detected" result:

- Further clinical evaluation or diagnostic workup, such as an echocardiogram
- More frequent follow-up
- Close attention to Heart Failure symptoms such as shortness of breath, fatigue, and swelling of the legs and feet

Low LVEF Not Detected Result

Clinicians should continue to monitor these patients in accordance with current medical practice standards. If there is suspicion of low LVEF or heart failure based on symptoms, risk factors or clinical signs, additional work-ups should continue to be ordered.

RESULTS DESCRIPTION

Low LVEF Risk Results

Results of the device are reported as "Low LVEF Detected" or as "Low LVEF Not Detected" to indicate the detection of signs associated with a patient having a low LVEF of ≤40%.

A Low LVEF Detected result should be evaluated in conjunction with other available clinical information to help inform the need for further diagnostic follow-up. Typical diagnostic follow-up testing could include echocardiography to confirm presence of low LVEF. Results do not establish a diagnosis of low LVEF at the time of the test and do not mean that low LVEF will definitely be present. Positive results should not be used as a criterion for treatment with any medications.

A Low LVEF Not Detected result does not rule out current low LVEF or mean that a patient will not develop low LVEF in the future. Patients should continue to be evaluated in accordance with current medical practice standards using all available clinical information.

Results should be considered in accordance with the established performance of the test for predicting low LVEF, as described in the *Model Training and Performance Testing* section. Any decisions related to patient care should be based on the independent judgment of the treating clinical provider.

Unclassifiable ECG

An "unclassifiable" result indicates that input data do not meet input data specifications.

A result of "unclassifiable" will be generated if the input data, including the ECG tracing, fails any input data checks. The device will return an "unclassifiable" result and an associated error code for any of the following reasons:

Error Code 00001	Not in use
Error Code 00002	The patient age on the ECG is below 40
Error Code 00003	The patient age could not be determined
Error Code 00004	The manufacturer name is not GE Healthcare or Philips
Error Code 00005	The sample rate of the ECG is not 500Hz
Error Code 00006	The sample count of the ECG is not 5000
Error Code 00007	Not in use
Error Code 00008	Not in use
Error Code 00009	Lead data exceeded the max voltage threshold of 9mV
Error Code 00010	Lead data has a flat line greater than 1 second
Error Code 00011	Lead data is not at least 10 seconds long
Error Code 00012	Baseline wander was detected in a lead
Error Code 00013	Motion artifact noise was detected in a lead
Error Code 00014	Powerline interference was detected in a lead
Error Code 00015	The patient sex on the ECG is not Male or Female
Error Code 00016	Lead data was empty
Error Code 00017	The data passed to the device was not in the form of the input specification
Error Code 00018	Lead data was not in the form of an int16 array
Error Code 00019	Lead data has a high-pass filter >1 Hz
Error Code 00020	Lead data has a low-pass filter <40 Hz
Error Code 00021	Lead data has a high-pass filter <0.05 Hz
Error Code 00022	Lead data has a low-pass filter >150 Hz

If you receive a result of "unclassifiable", please submit a new ECG that meets the input data requirements. For details on input data requirements, see *Specifications*.

SPECIFICATIONS

Input Data

The device requires data and metadata from a 10 second 12-lead resting electrocardiogram recording, including:

- **Lead trace data** from the input ECG including Lead I, Lead II, Lead V1, Lead V2, Lead V3, Lead V4, Lead V5, Lead V6, as base64 encoded strings of signed 16-bit integer arrays with complete voltage-time traces of 10 seconds

- **Sample rate** in Hz as a string that equals "500"
- **Sample count** as a string that equals "5000"
- **Lead amplitude per bit** as a string representing microvolts per bit, greater than 0μV and less than or equal to 5μV
- Acceptable values of a high-pass filter between 0.05 Hz and 1 Hz
- Acceptable values of a low-pass filter between 40 Hz and 150 Hz
- **Patient sex** as a string of "male" or "female"
- **Patient age** in unit values of years, months, weeks, days, or hours, or date of birth and recording acquisition date, with a value greater than or equal to 40 years
- **Manufacturer** of the input ECG as either "GE Healthcare" or "Philips"

The device is only compatible with ECG recordings collected using 'wet' Ag/AgCl electrodes with conductive gel/paste, and using FDA authorized resting 12-lead resting ECGs from GE Medical Systems (e.g., CSYS, LP15, M1200, MAC2K, MAC35, MAC55, MAC5K, etc.) and Philips Medical Systems (e.g., PageWriter TC and PageWriter Touch).[1]

Output Data

See *Interpretation of Results* section.

MODEL TRAINING AND PERFORMANCE TESTING

The Tempus ECG-Low EF algorithm was developed using an extensive training dataset of patients and ECGs and tested in a performance study to establish performance in the population in which the device is intended to be used.

The training dataset comprised more than 172,662 unique patients contributing 930,689 ECGs across 9 distinct hospitals and clinics. This dataset was used to train a machine-learning model via supervised learning. The model was trained to identify patients with low LVEF based solely on ECG data. Demographic characteristics of the training dataset are described in Table 1.

The performance of Tempus ECG-Low EF in identifying patients who have low LVEF as determined by echocardiogram was evaluated in a retrospective study.

This study used a real-world dataset of patients from 4 geographically distinct sites with a range of clinically-used ECG machines. Nine models of 12-lead ECG machines were included in the study to provide ECG inputs to the Tempus ECG-Low EF software. These were: CSYS, LP15, M1200, MAC2K, MAC35, MAC55 and MAC5K (GE Medical Systems) and PageWriter TC and PageWriter Touch (Philips Medical Systems). No data present in the training dataset were used in the performance study. In the performance study, Tempus ECG-Low EF was applied to patients meeting inclusion/exclusion criteria who received a 12-lead ECG, comprehensively capturing the intended use population. All patients in the performance study had a clinically acquired ECG and were age 40 or greater at the time of the ECG. Demographic characteristics of the training data and performance study data are described in Table 1. The low LVEF status of each patient was determined by echocardiogram. Results of "Low LVEF Detected" or "Low LVEF Not Detected" were generated by Tempus ECG-Low EF and compared to the LVEF status to establish device performance.

Table 1. Demographic and Clinical Characteristics of the Training Datasets and Performance Study Dataset*

PARAMETER	PERFORMANCE STUDY	TRAINING DATASET
N	**14,924**	**930,689**
Age (in years)		
Mean (SD)	**70 (13)**	**66 (15)**
Median	**70**	**68**
Q1/Q3	**61-80**	**57-77**
Min/Max	**40-90**	**18-90**
Age (%)		
<65	**5,277 (35)**	**387,889 (42)**
≥65	**9,647 (65)**	**540,456 (58)**
Unknown		**2,344 (<1)**
Sex (%)		
Female	**7,284 (49)**	**466,701 (50)**
Male	**7,640 (51)**	**461,287 (50)**
Unknown		**2,701 (<1)**
Race (%)		
White	**11,842 (79)**	**904,274 (97)**
Black	**2,028 (14)**	**14,381 (2)**
Asian	**291 (2)**	**3,998 (<1)**
Other	**584 (4)**	**2,908 (<1)**
Unknown	**179 (1)**	**5,128 (1)**
Ethnicity (%)		
Hispanic	**1,344 (9)**	**13,506 (1)**
Not Hispanic	**13,514 (91)**	**845,441 (91)**
Unknown	**66 (<1)**	**71,742 (8)**
BMI (%)		
<18.5	**367 (3)**	**16,449 (2)**
[18.5, 25)	**3,315 (22)**	**164,447 (18)**
[25, 30)	**4,244 (28)**	**236,550 (25)**
≥30	**6,456 (43)**	**380,846 (41)**
Unknown	**542 (4)**	**132,397 (14)**
Clinical condition**		
Atrial fibrillation	**6,223 (42)**	**401,967 (43)**
Aortic stenosis	**1,877 (13)**	**181,235 (19)**
Cardiomyopathy	**2,344 (16)**	**106,350 (11)**
Diabetes	**7,422 (50)**	**461,920 (50)**
Hypertension	**13,226 (89)**	**805,104 (87)**
Ischemic heart disease	**8,348 (56)**	**580,404 (62)**
Myocardial infarction	**3,369 (23)**	**308,962 (33)**
Mitral regurgitation	**1,832 (12)**	**195,385 (21)**

** Counts are based on ECG-level metrics. Note that for the performance study, there is only one ECG per patient.*

*** Columns sum to >100% because patients can have more than one of the included conditions.*

The established performance of Tempus ECG-Low EF is based on

the performance characteristics demonstrated in the performance study, as shown in Tables 2 and 3.

Table 2. Device Performance (Performance Study Dataset)

Low EF prevalence	**10.7%**
Sensitivity *(95% CI)*	**86%** *(84%, 87%)*
Specificity *(95% CI)*	**83%** *(82%, 84%)*
Positive predictive value *(95% CI)*	**38%** *(36%, 39%)*
Negative predictive value *(95% CI)*	**98%** *(98%, 98%)*

Table 3. Confusion Matrix (Performance Study Dataset)

		ACTUAL (FROM ECHO)		
		LVEF ≤40%	**LVEF >40%**	**Total**
PREDICTED (DEVICE RESULT)	**"Low LVEF Detected" (positive)**	**1,369**	**2,263**	**3,632**
	"Low LVEF Not Detected" (negative)	**227**	**11,065**	**11,292**
	Total	**1,596**	**13,328**	**14,924**

Tempus ECG-Low EF demonstrated a sensitivity of 86% for classifying patients with low LVEF and a specificity of 83% for classifying patients that did not have low LVEF. The positive predictive value (PPV) was 38%, meaning that 38 out of every 100 patients classified as "Low LVEF Detected" had low LVEF by echocardiogram. The negative predictive value (NPV) was 98%, meaning that 98 out of every 100 patients classified as "Low LVEF Not Detected" did not show low LVEF by echocardiogram. The prevalence of low LVEF in the performance study was 10.7%.

Sensitivity, specificity, and prevalence can be used to calculate the number of people tested to identify one patient with low LVEF. Based on the performance study results, for every 100 patients tested with ECG-Low EF, approximately 24 will be flagged as "Low LVEF Detected", and approximately 9 of those 24 patients will have clinical low LVEF when tested by echocardiogram.

1 Product and company names of GE and Philips are trademarks of their respective owners. Use does not imply affiliation or endorsement.

TECHNICAL SUPPORT

For technical support or inquiries, please contact the Tempus Cardiology Support team at support@tempus.com or by calling 800.739.4137.