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A Patch Wearable Cardioverter-Defibrillator for Patients at Risk of Sudden Cardiac Arrest

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ABSTRACT

BACKGROUND For many patients, sudden cardiac arrest (SCA) risk is elevated temporarily. Wearable cardioverter-defibrillators (WCDs) can monitor and treat SCA during these temporary periods. Traditional WCDs can be uncomfortable, require frequent maintenance, and cannot be used when showering, resulting in poor compliance and avoidable SCA deaths. The Jewel is a novel, water-resistant patch-wearable cardioverter-defibrillator (P-WCD) with a machine learning detection algorithm designed to improve compliance and protection against SCA.

OBJECTIVES This study aims to demonstrate the safety and clinical effectiveness of a novel P-WCD.

METHODS The Jewel IDE Study, a prospective, single-arm study conducted at 30 U.S. sites, enrolled patients at SCA risk due to ventricular tachycardia/ventricular fibrillation who were not candidates for or refused an implantable defibrillator. The primary safety endpoint was <15% patients with clinically significant cutaneous adverse device effects and the primary effectiveness endpoint was <2 inappropriate shocks/100 patient-months. Secondary endpoints were ≥1 successful ventricular tachycardia/ventricular fibrillation conversion and wear time compliance of >14.1 h/d.

RESULTS A total of 305 patients (mean age: 57.9 years; 30.2% female, 27.9% non-White) were enrolled, of which 290 had available device data. The clinically significant cutaneous adverse device effect rate was 2.30% (upper 1-sided 98% CI: 4.80); none were severe. No device-related deaths or serious adverse events were reported. The inappropriate shock rate was 0.36/100 patient-months (upper 1-sided 98% CI: 1.53). Of 11 shocks in 9 patients, 9 shocks were adjudicated to be appropriate. Eight of 9 shocks were successful with a single shock. Median wear time compliance was 23.5 (20.7-23.9) h/d.

CONCLUSIONS The novel P-WCD is a safe and effective WCD with high patient compliance. There were no deaths due to noncompliance and a high number of successful conversions (Jewel IDE study [A Clinical Evaluation of the Jewel P-WCD in Subjects at High Risk for Sudden Cardiac Arrest]; NCT05201495) (J Am Coll Cardiol 2024;84:525-536) © 2024 The Authors. Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

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The authors attest they are in compliance with human studies committees and animal welfare regulations of the authors' institutions and Food and Drug Administration guidelines, including patient consent where appropriate. For more information, visit the Author Center.

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ABBREVIATIONS AND ACRONYMS

ADE = adverse device effect

ICD = implantable cardioverter defibrillator

IDE = investigational device exemption

P-WCD = patch-wearable cardioverter defibrillator

SCA = sudden cardiac arrest

VF = ventricular fibrillation

VT = ventricular tachycardia

WCD = wearable cardioverter-defibrillator

Sudden cardiac arrest (SCA) due to ventricular tachycardia (VT)/fibrillation (VF) remains an important cause of death, with most deaths due to SCA occurring out of the hospital.[1-5] Timeliness of defibrillation is the most important predictor of survival.[3-5] Whereas implantable cardioverter-defibrillators (ICDs) may be indicated for patients at risk of SCA, there are temporary periods of elevated risk during which patients may not have an ICD.[6-10] In these cases, wearable cardioverter-defibrillators (WCDs) can be used to provide temporary protection until a patient is no longer at risk or an ICD can be implanted.[11] WCDs are noninvasive devices capable of continuously monitoring heart rhythms in patients at risk of SCA and automatically treating VT/VF without bystander assistance. Guideline-recommended WCD use is in patients at risk of SCA when clinical improvement is anticipated or if a temporary contraindication to ICD exists.[11] It is estimated that ~435,000 individuals are candidates for WCD therapy annually[12-18]; however, only approximately one-third of them are prescribed a WCD.[19,20] Data on available WCDs have shown mixed results, which may be related to noncompliance, patient discomfort, maintenance needs, and limitations during activity and showering. This noncompliance ultimately has resulted in avoidable arrhythmic deaths.[21]

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The Jewel is a novel, water-resistant patch-wearable cardioverter-defibrillator (P-WCD, Element Science, Inc) designed to enhance compliance by optimizing comfort, reducing maintenance and patient involvement, and allowing use during most activities, including showering, sleeping, and moderate exercise. The P-WCD's machine learning-based detection and treatment algorithm was developed to minimize inappropriate detections and provide effective protection against SCA. The defibrillation effectiveness of the P-WCD was successfully shown in a first-in-human study of individuals who were already undergoing an electrophysiology procedure lab study in which they would be induced into VT/VF.[22] The Jewel Investigational Device Exemption (Jewel IDE) study assessed the safety and effectiveness of the P-WCD for monitoring, detecting, and terminating sustained VT/VF ("shockable rhythms") in a population typically indicated for WCDs.

METHODS

STUDY DESIGN AND OVERSIGHT. This study (NCT05201495) was a multicenter, prospective, single-arm study of adult patients at risk of SCA who were not candidates for or who refused an ICD. The study was funded by Element Science, Inc, and was approved by the Institutional Review Board at each enrolling center (Supplemental Appendix). All the statistical analyses were performed by an independent statistician. All investigators had full access to the data, revised the manuscript, supported the decision to submit the manuscript for publication, and can attest to the fidelity of the trial and associated data. The data that support the findings of this study are available from the corresponding author upon reasonable request.

An independent data and safety monitoring board oversaw patient safety and study conduct.

PATIENT POPULATION. Adult patients at risk for SCA who were not candidates for or who refused an ICD were eligible, including those: 1) who had a left ventricular ejection fraction ≤40%[23]; 2) who had a contraindication for an ICD, had an ICD removed, or refused an ICD; or 3) whose ICD implantation was delayed due to COVID-19 infection or exposure-related risks. A full list of the eligibility criteria is summarized in Supplemental Table 1 and all patients enrolled in the study gave written informed consent.

After obtaining informed consent, eligible patients were enrolled, trained, and fitted with the P-WCD by a representative of Element Science, Inc, after which they left with the device on body. Training consisted of an in-person session in which medical history, device components, fitting, and usage were reviewed. The prescription period was determined by their physician. Physicians had the discretion to curtail use as clinically indicated or extend use up to a maximum of 180 days (to allow for timely completion of the study). After enrollment, patients were followed up and data were collected per the schedule presented in the Supplemental Appendix.

DEVICE CHARACTERISTICS. The P-WCD comprised of one monitoring and defibrillation unit and an 8-day patch and battery unit (**Central Illustration**) that can be worn continuously for up to 8 days after which

the patient removes the old patch and battery unit, attaches a new one, and reapplies the P-WCD. The monitoring and defibrillation unit is durable and can be used throughout the duration of a prescription. If a patient's monitoring and defibrillation unit becomes damaged or nonfunctional, a new one is provided. The P-WCD continuously monitors a patient's cardiac rhythm through electrodes located on the adhesive patches and uses a machine learning algorithm to detect and treat sustained, shockable rhythms. The period during which a patient uses a single patch and battery unit is referred to as an individual wear.

The P-WCD continuously monitors for sustained, shockable rhythms (ie, VT/VF). If a sustained shockable rhythm is continuously detected for 24 seconds, the P-WCD initiates the charge cycle of the capacitors and, in parallel, the P-WCD issues an alarm and continues to monitor the rhythm. If the patient is conscious, the patient can defer shock delivery by pressing the control buttons on the device. If the patient does not respond and the P-WCD continues to detect a shockable rhythm, it will continue to alarm, will give a verbal warning to bystanders to avoid touching the patient, and will then deliver an initial shock of 150 J <60 seconds after initial detection of the shockable rhythm. Therapy is delivered using a biphasic truncated exponential defibrillation waveform using a constant energy pulse that is adjusted based on the measured transthoracic impedance. The biphasic truncated exponential waveform used is similar to the waveform used for other commercially available defibrillators. If R waves are detected, the P-WCD attempts to perform synchronized cardioversion. After the initial shock, if the shockable rhythm persists, the P-WCD re-initiates the alarm and warning sequences and can deliver a salvo of up to 4 additional shocks of 162 J each. The P-WCD is designed to deliver up to 2 salvos of 5 shocks or up to 10 individual shocks and cannot be reconfigured by the prescribing physician. When the P-WCD no longer detects a shockable rhythm, it will continue monitoring for the occurrence of a new shockable rhythm and will direct bystanders to call 911 and start cardiopulmonary resuscitation efforts.

SAFETY AND EFFECTIVENESS ENDPOINTS. The primary safety endpoint was a rate of patients experiencing a clinically significant cutaneous adverse device effect (ADE) of <15%. A cutaneous ADE was considered clinically significant if it resulted in a physician withdrawing a patient from the study, regardless of event severity. The clinically significant cutaneous ADE rate was selected as the primary safety endpoint to ensure that the adhesive-based design could be safely used without adversely affecting compliance. The endpoint for clinically significant cutaneous ADE rate was chosen as 15% to be in line with incidence of skin-related adverse events for other commercially available WCDs.[21,24]

The primary effectiveness endpoint was an inappropriate shock rate of <2.0 per 100 patient-months, based on the inappropriate shock rate of other commercially available WCDs.[21] The secondary effectiveness endpoints were: 1) >1 successful conversion of a shockable rhythm using up to a full salvo of shocks (1-5 shocks); and 2) a compliance rate of patient wearing P-WCD for >14.1 average hours per day during the wear period, based on compliance rates for other commercially available WCDs.[21]

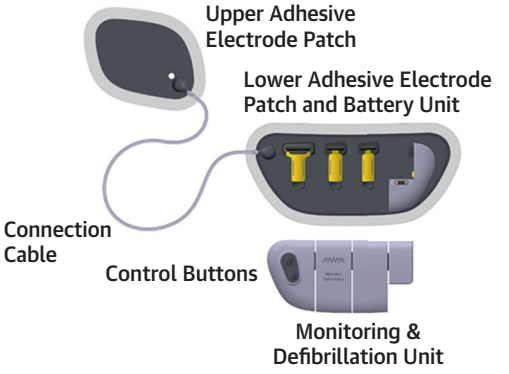
STATISTICAL ANALYSIS. Based on inappropriate shock rates from currently available WCDs, a sample of 290 patients with analyzable wear time was determined to provide >98% power with a 1-sided upper 98% CI.[25] Given the aim to assess long-term performance in a real-world ambulatory population, patients who exited within the first 12 hours (n = 6) were excluded. A detailed rationale for the sample size calculation and endpoints is presented in the Supplemental Appendix.

For the primary safety endpoint, a one-sided, upper 98% CI limit was calculated based on the Clopper-Pearson method and compared to the performance goal of 15%.[26] The safety analysis consisted of all enrolled patients except those who exited in the first 12 hours following application of their first P-WCD.

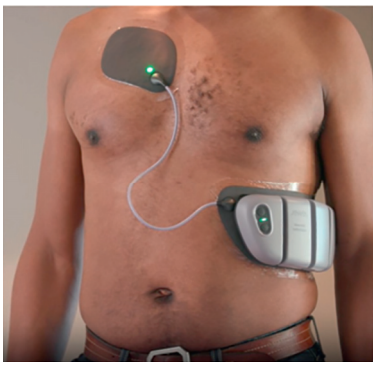
For the primary effectiveness endpoint, a 1-sided upper 98% CI limit was calculated for the inappropriate shock rate per 100 patient-months using an intercept-only Poisson regression model. The effectiveness analysis consisted of all patients who had returned at least 1 device (N = 290) and therefore had analyzable wear times, defined as beginning 12 hours after the P-WCD was applied to when the P-WCD was removed, excluding periods when the P-WCD was off the body and periods of time in which there were missing data due to devices that were lost or not

CENTRAL ILLUSTRATION The Jewel Patch Wearable Defibrillator

A Schematic Diagram of P-WCD

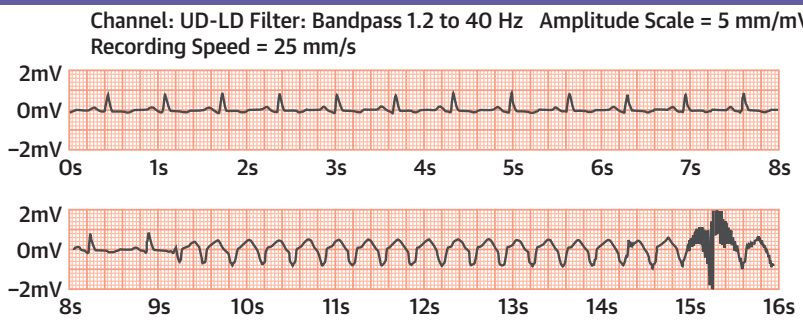


B P-WCD Applied to Patient

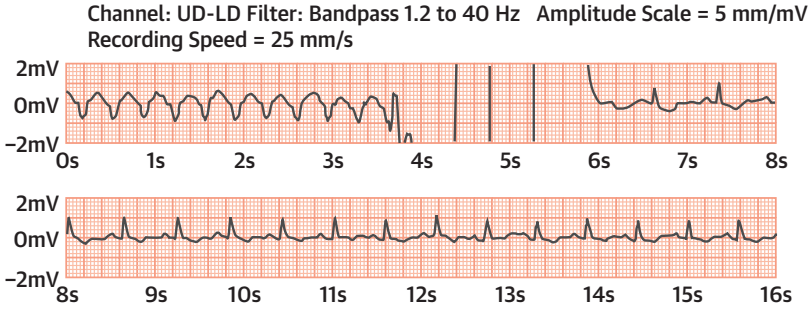


C Appropriate Shock Event in Jewel IDE Study

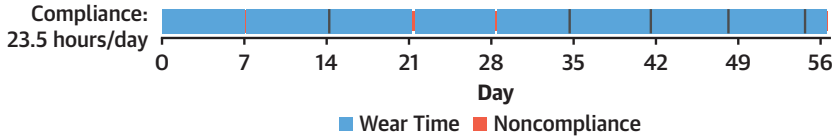
Onset of Episode



Shock Delivered During Episode



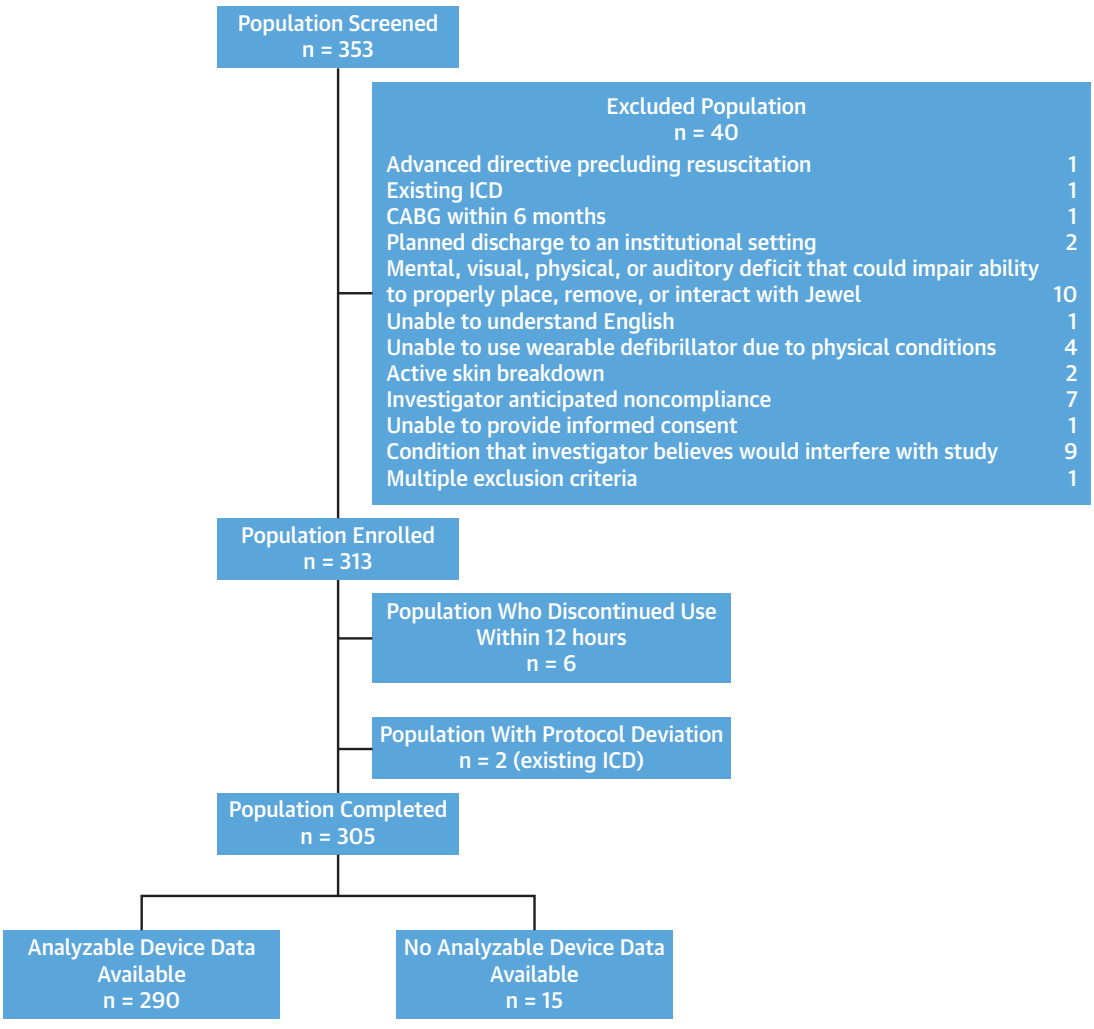
D Compliance Across Typical Patient Prescription



Hummel J, et al. J Am Coll Cardiol. 2024;84(6):525–536.

(A) The components of the patch-wearable cardioverter-defibrillator (P-WCD) including the upper adhesive electrode patch, the lower adhesive electrode patch and battery unit, the monitoring and defibrillation unit, the connection cable, and the control buttons. (B) The P-WCD as worn on a patient during the application process. (C) An appropriate shock event of a study patient in which monomorphic ventricular tachycardia was successfully defibrillated with subsequent return of sinus rhythm. (D) Compliance across the duration of a typical patient prescription (compliance from the 50th percentile patient depicted). IDE = investigational device exemption.

FIGURE 1 **Consolidated Standards of Reporting Trials Diagram Showing Patient Selection Schema**



Among the 313 individuals enrolled in the study, 6 discontinued use of the device after 12 hours and were therefore excluded from the study, and 2 individuals were excluded as protocol deviations due to existing implantable cardioverter-defibrillators (ICDs). Of the 305 individuals who completed the study, 290 had analyzable device data and 15 did not return their patch-wearable cardioverter-defibrillator. All 305 individuals were included in the safety analysis; 290 individuals with analyzable device data were included in the effectiveness analysis. CABG = coronary artery bypass graft.

returned by patients. Consistent with the period in which all adverse events were ascertained, the total study participation periods for each patient were accounted for when calculating the inappropriate shock rate. The null hypothesis was rejected if the upper 95% CI limit of the inappropriate shock rate was <2.0.

For the secondary effectiveness endpoint of successful conversion, a shock was considered appropriate if delivered during a period in which the patient was experiencing a sustained shockable rhythm. The number and percentage of successful conversions to a nonshockable rhythm are reported. A clinical events committee adjudicated all clinically

TABLE 1 Baseline Demographic and WCD Characteristics of Patients Enrolled in the Jewel IDE Study (N = 305)

Demographic	
Age, y	57.9 ± 13.3
Age	60.0 (21.8-88.7)
Female	92 (30.2)
Not Hispanic or Latino	293 (96.1)
Race	
White	220 (72.1)
Black or African American	74 (24.3)
Asian	4 (1.3)
American Indian or Alaska Native	
Native Hawaiian/Other Pacific Islander	
Other	8 (2.6)
Body Mass Index, kg/m^2	30.0 ± 6.7
Clinical	
Prior MI	97 of 303 (32.0)
Prior CABG	35 of 303 (11.6)
Prior PCI	113 of 303 (37.3)
Prior CHF	221 of 303 (72.9)
Atrial fibrillation	79 of 303 (26.1)
Unstable angina	38 of 297 (12.8)
Prior VT	62 of 303 (20.5)
History of sudden cardiac arrest	28 of 303 (9.2)
Hypertension	216 of 303 (71.3)
Smoking	139 of 303 (45.9)
Diabetes	103 of 303 (34.0)
Prior COVID-19 infection	61 of 303 (20.1)
Baseline medication use	
ACEI/ARB/ARNI	202 of 287 (70.4)
Amiodarone	50 of 287 (17.4)
Other antiarrhythmic agent	4 of 287 (1.4)
Anticoagulation	91 of 287 (31.7)
Other antiplatelet agent	84 of 287 (29.3)
Aspirin	144 of 287 (50.2)
Beta-blocker	233 of 287 (81.2)
Calcium-channel blocker	24 of 287 (8.4)
Digoxin	5 of 287 (1.7)
Diuretic	136 of 287 (47.4)
Other lipid-lowering agent	15 of 287 (5.2)
Mineralocorticoid receptor antagonist	112 of 287 (39.0)
SGLT2i	98 of 287 (34.1)
Statin	172 of 287 (59.9)

Continued on the next page

significant cutaneous ADEs and all shocks during analyzable wear time.

For the secondary effectiveness endpoint of the observed compliance rate, average daily wear time was calculated as follows:

$$\frac{(\textit{Total wear time} - \textit{Sum of gaps between individual wears})}{\textit{Total wear time (expressed in days)}}$$

Total wear time was defined as 12 hours after the P-WCD was applied and began monitoring heart rhythm to the time when the P-WCD from a patient's last wear was removed, excluding periods where device removal was medically recommended. Patient compliance was assessed using time-stamped data recorded and stored by the P-WCD. Patients experiencing an inappropriate shock continued to be followed to collect data on compliance. All analyses were performed using SAS version 9.4.

RESULTS

DEMOGRAPHIC AND CLINICAL CHARACTERISTICS. The study enrolled 305 patients from 30 U.S. sites between January 12, 2022, and May 18, 2023, of which 290 returned at least 1 device. Fifteen patients did not return their P-WCD from which analyzable wear time would have been extracted and therefore were excluded from the effectiveness analyses but were included in the safety analyses. **Figure 1** shows the population who was screened, enrolled, and who completed the study.

Baseline patient characteristics and P-WCD use of the 305 enrolled patients are presented in **Table 1**. Patient characteristics of the 290 patients with analyzable wear time are presented in Supplemental Table 2. Among the 305 patients, the average age was 57.9 ± 13.3 years, 92 (30.2%) were female and 85 (27.9%) identified as non-White. Mean body mass index was 30.0 ± 6.7 kg/m^2. In the study, 72.9% of patients had heart failure, 32.0% had a prior myocardial infarction, 20.5% had history of VT, and 18.8% were on an antiarrhythmic medication. The most common indications for P-WCD prescription were nonischemic cardiomyopathy (35.1%) and a temporary contraindication to ICD (26.2%). Mean study participation duration was 59.3 ± 45.0 (median: 49 days; Q1-Q3: 23-90 days).

Reasons for investigator- and patient-initiated study exits for all patients in the study are summarized in **Table 2**. The most frequent reason for investigator-initiated study exit was WCD no longer being indicated (n = 153, 50.16%), and the most frequent reason for patient-initiated study exit was skin-related concerns (n = 37, 12.13%). Description of study exits by timing and whether they were clinically indicated are shown in **Figure 2**. Overall, 163 patients (53.4%) exited for clinically indicated reasons.

P-WCD SAFETY. Of 305 patients analyzed for the safety endpoint, 7 (2.30%, upper 1-sided 98% CI: 4.80%) experienced a clinically significant cutaneous ADE, which met the prespecified primary safety endpoint of <15%. All clinically significant cutaneous ADEs were moderate in severity.

Among the 305 patients, 175 patients (57.4%) experienced no ADEs. Of the patients reporting any ADE, 23 (7.54%) exited the study due to a reported ADE (Table 3). A total of 155 ADEs were reported (Table 4). Of these, 70.9% were mild, and the most common reason was rash (n = 107, 69.0%). There were no severe ADEs. Overall, 85.2% of ADEs did not result in patient exit from the study.

Among enrolled patients, 179 (61.7%) experienced 0 alarms, and 258 (88.9%) experienced <1 alarm per day over the study period. Of the false alarms, 76.3% in the study were clustered in 5 patients. The overall median false alarm rate was 0 alarms per day (Q1-Q3: 0-2.42).

P-WCD EFFECTIVENESS. Nine patients (3.0%) experienced a total of 11 shocks; 7 were on amiodarone before shock. Of 11 shocks, 9 were adjudicated as appropriate, 1 as inappropriate by the CEC (Clinical Events Committee) but appropriate by site investigator, and 1 as inappropriate by both CEC and site investigator (Table 5). Among the 290 patients with device data, the rate of shocks adjudicated as inappropriate was 0.36 per 100 patient-months (upper 98% CI: 1.53), which met the prespecified endpoint of <2.0 per 100 patient-months.

Of the 9 adjudicated appropriate shocks, 8 were successful, meeting the secondary effectiveness endpoint of observing at least 1 successful conversion of a shockable rhythm. In the remaining patient, who was getting ready for hospital discharge, the success of a salvo of shocks could not be determined as the P-WCD was removed after an initial unsuccessful shock and replaced by an external defibrillator per hospital protocol. All successful conversions occurred with the first shock. An example of a successful defibrillation of a study participant is shown in panel 1C of the **Central Illustration**.

USER WEAR COMPLIANCE. Mean daily wear time among 290 patients with device data was 21.3 ± 4.48 h/d (median: 23.5; Q1-Q3: 20.7-23.9 h/d), corresponding to a median compliance of 97.8% (Q1-Q3: 86.1%-99.7%). Among the 290 patients, 264 (91.0%) wore the P-WCD for longer than the prespecified threshold of 14.1 hours per day.

TABLE 1 Continued

WCD indication	
Acute myocardial infarction	42 (13.8)
NSTEMI	15 (35.7)
STEMI	27 (64.3)
ICD implant delayed due to COVID-19 infection or exposure-related risks	1 (0.3)
ICD removal	5 (1.6)
Ischemic cardiomyopathy	52 (17.0)
Long-term contraindication to ICD	4 (1.3)
Myocarditis	2 (0.7)
Nonischemic cardiomyopathy	107 (35.1)
Patient refuses ICD	12 (3.9)
Temporary contraindication to ICD	80 (26.2)
Anticipated prescription length, d	
40	20 (6.6)
90	195 (63.9)
Other	90 (29.5)
Anticipated prescription length, d	
Mean ± SD	91.9 ± 37.8
Median (Q1-Q3)	90.0 (90.0-90.0)
Min to max	6 to 180

Values are mean ± SD, median (Q1-Q3)), or n (%).

ACEI = angiotensin-converting enzyme inhibitor; ARB = angiotensin receptor blocker; ARNI = angiotensin receptor neprilysin inhibitor; CABG = coronary artery bypass graft; CHF = congestive heart failure; ICD = implantable cardioverter-defibrillator; Max = maximum; MI = myocardial infarction; Min = minimum; NSTEMI = non-ST-segment elevation myocardial infarction; PCI = percutaneous coronary intervention; SGLT2i = sodium-glucose cotransporter 2 inhibitor; STEMI = ST-segment elevation myocardial infarction; VT = ventricular tachycardia; WCD = wearable cardioverter-defibrillator.

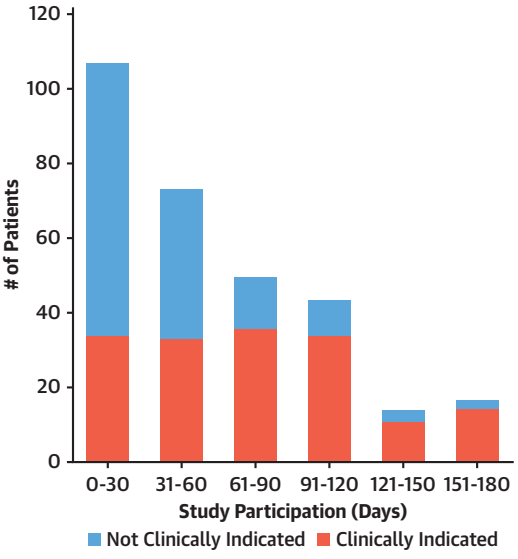
TABLE 2 Reasons for Patient Exits[a]

	n %
Investigator initiated	
WCD no longer indicated (EF improvement, ICD placed, investigator determination)	153 (50.2)
Patient lost to follow-up	15 (4.9)
Clinically significant cutaneous ADE	7 (2.3)
Noncompliance	7 (2.3)
Newly developed exclusion criterion or medical condition precluding P-WCD use	6 (2.0)
Other	4 (1.3)
Completed maximum study prescription (180 days)	2 (0.7)
Disease progression	2 (0.7)
Patient initiated	
Skin-related concerns	37 (12.1)
User experience concerns	23 (7.5)
Other	19 (6.2)
Alert-related concerns	10 (3.3)
Combination[b]	10 (3.3)
Patient discomfort	8 (2.6)
Unrelated medical conditions[c]	2 (0.7)
Total	305 (100.0)

[a]Exit reasons were not all associated with a reported ADE. [b]Combination includes reasons encompassing 2 or more of the above categories [c]Unrelated medical conditions include conditions that did not preclude P-WCD usage, but due to which the patient decided to forego participation in the study.

ADE = adverse device effect; EF = ejection fraction; ICD = implantable cardioverter-defibrillator; P-WCD = patch-wearable cardioverter-defibrillator; other abbreviation as in Table 1.

FIGURE 2 Jewel IDE Study Patient Exits



The bar chart depicts patient exits in the Jewel IDE study categorized by duration (days) of study participation, and whether the study exit was clinically indicated. Clinically indicated patient exits included the following study exit reasons: newly developed exclusion criterion on medical condition precluding patch-wearable cardioverter-defibrillator use, completed maximum study prescription (180 days), disease progression, and wearable cardioverter-defibrillator no longer indicated. Overall, 163 patients (53.4%) exited for clinically indicated reasons and nonclinically indicated study exits decreased over time. IDE = investigational device exemption.

TABLE 3 Summary of Patients Reporting and Exiting Due to Adverse Device-Related Effects Over the Study Wear Period Stratified by ADE Type

	Patients Reporting ADE[a]		Patients Who Exited Due to Reported ADE	
	n	% of Study Population	n	% of Study Population
Rash[b]	96	31.5	22	7.2
Skin injury[c]	13	4.3	0	0.0
Patient discomfort[d]	23	7.5	1	0.3
Device issue[e]	1	0.33	0	0.0

[a]Patients may have reported multiple types of ADEs and therefore may be counted in multiple ADE categories. Patient exits were attributed to individual ADEs and therefore each patient is only represented once. [b]Rash includes the following MedDRA preferred terms: dermatitis acneiform, application site erythema, application site rash, application site urticaria, application site vesicles, cellulitis, blister, erythema multiforme, medical device site rash, skin lesion, dermatitis, contact skin irritation, erythema, rash, rash erythematous, rash vesicular, and urticaria. [c]Skin injury includes the following MedDRA preferred terms: application site bruise, application site injury, application site laceration, skin disorder, skin exfoliation, skin hyperpigmentation, wound, skin erosion, contusion, and skin injury. [d]Patient discomfort includes the following MedDRA preferred terms: application site burn, application site irritation, application site pain, application site pruritis, application site reaction, pruritis, medical device site pain, skin burning sensation, abdominal pain lower, tenderness, burning sensation, paresthesia, and medical device site irritation. [e]Device issue includes the following MedDRA preferred terms: device issue and shock.

MedDRa = Medical Dictionary for Regulatory Archives; other abbreviation as in Table 2.

DISCUSSION

In this multicenter, prospective, single-arm study, the safety and effectiveness of a novel, water-resistant P-WCD was studied in 305 patients who met typical WCD intended-use criteria. The demographics of the enrolled study population are comparable to studies of predicate devices and are representative of the patient population with indications for WCDs.[21,27] Whereas studies of predicate WCDs focused on subpopulations of individuals indicated for a WCD (eg, postmyocardial infarction in the VEST [Vest Prevention of Early Sudden Death Trial]), this study enrolled a broad patient population indicated for a WCD. Use of these predicate WCDs has been limited largely due to patient noncompliance related to inconveniences associated with prolonged use of garment-based devices. The results of this study show that a novel P-WCD, which is the first adhesive-based wearable defibrillator to our knowledge, successfully met the prespecified primary and secondary endpoints for safety and effectiveness with no deaths due to noncompliance.

With an adhesive-based design, a key question was safety with respect to skin-related ADEs. This study showed a low rate (2.3%) of clinically significant cutaneous ADEs (cutaneous ADEs resulting in a physician withdrawing a patient from the study) with no severe cutaneous ADEs reported. Prior data from garment-based WCDs did not report on clinically significant cutaneous ADEs as a safety outcome. VEST reported skin rashes in 15.3% of patients whereas the average wear time was only 14.0 hours per day.[21] In the ACE-DETECT (ASSURE WCD Clinical Evaluation-Detection and Safety Study), skin irritation occurred in 23.1% of patients with study participation limited to 30 days.[27] Overall, in the current study, 31.5% of patients experienced skin rashes and 4.3% experienced skin injury. However, only 2.3% of patients exited due to investigator decision and 7.2% of patients exited due to patient decision. The low percentage resulting in study exits suggests that skin-related events did not hinder patients from complying with life-saving therapy when needed.

In contrast, results from other commercially available WCDs reported deaths or potential missed shockable rhythms as a result of noncompliance, algorithm settings, or performance.[21,27] For example, in the VEST, 64% of the arrhythmic deaths occurred when patients assigned to the WCD group were not wearing the LifeVest.[21] In the ACE-DETECT study, the ASSURE WCD was placed with detection on and

TABLE 4 Summary of ADEs Reported Over the Study Wear Period Stratified by Type and Severity

		Mild ADE		Moderate ADE		Severe ADE	
	No. of ADEs	Resulting in Exit[a]	Not Resulting in Exit	Resulting in Exit[a]	Not Resulting in Exit	Resulting in Exit[a]	Not Resulting in Exit
Rash[b]	107	8	62	14	23	0	0
Skin injury[c]	14	0	13	0	1	0	0
Patient discomfort[d]	33	1	25	0	7	0	0
Device issue[e]	1	0	1	0	0	0	0

[a]ADEs resulting in exit were those that occurred within 8 days of patient exit to estimate the time course of the patient's last patch wear period. [b]Rash includes the following MedDRA preferred terms: dermatitis acneiform, application site erythema, application site rash, application site urticaria, application site vesicles, cellulitis, blister, erythema multiforme, medical device site rash, skin lesion, dermatitis, contact skin irritation, erythema, rash, rash erythematous, rash vesicular, and urticaria. [c]Skin injury includes the following MedDRA preferred terms: application site bruise, application site injury, application site laceration, skin disorder, skin exfoliation, skin hyperpigmentation, wound, skin erosion, contusion, and skin injury. [d]Patient discomfort includes the following MedDRA preferred terms: application site burn, application site irritation, application site pain, application site pruritis, application site reaction, pruritis, medical device site pain, skin burning sensation, abdominal pain lower, tenderness, burning sensation, paresthesia, and medical device site irritation. [e]Device issue includes the following MedDRA preferred terms: device issue and shock.

Abbreviations as in Tables 2 and 3.

TABLE 5 Adjudication of Shock Events During the Jewel IDE Study

	Rhythm Adjudication	Investigator Notes	On Antiarrhythmic Medication? Y/N	WCD Indication	Days Since Enrollment	Investigator Assessment	Final Adjudication	Outcome
1	Polymorphic VT/VF	"Passed out," loss of bowel and bladder function VT	Y	Acute MI	6	Appropriate	Appropriate	Successful single shock conversion, received ICD
2	SVT with underlying LBBB	"Tunnel vision, ringing in ears, found face down in dirt" Polymorphic VT	N	Nonischemic cardiomyopathy	30	Appropriate	Inappropriate	Successful single shock conversion, received CRT-D
3	Polymorphic VT/VF	"Passing out" while driving Polymorphic VT/VF in setting of LBBB	Y	Temporary contraindication to ICD	17	Appropriate	Appropriate	Successful single shock conversion, received CRT-D
4	Coarse VF	Found unconscious in hospital bathroom VF	N	Ischemic Cardiomyopathy	1	Appropriate	Appropriate	Initial shock delivered and P-WCD replaced by external defibrillator used per hospital resuscitation protocol, therefore success of conversion could not be determined
5	VT	Lightheadedness, palpitations Monomorphic VT storm	Y	Acute MI	6	Appropriate	Appropriate	Successful single shock conversion, received ICD
6	Sinus Tachycardia	Shortness of breath Patient was conscious; deferred alarms and then allowed device to deliver shock, against intended use and training received Sinus tachycardia	N	Acute MI	41	Inappropriate	Inappropriate	Continued to wear P-WCD until WCD was no longer indicated due to improvement in LVEF
7	Pleomorphic VT	Lightheadedness while driving Fast monomorphic VT	Y	Ischemic Cardiomyopathy	87	Appropriate	Appropriate	Successful single shock conversion, received CRT-D
8	Coarse VF	Initial presentation: syncope VT	Y	Acute MI	3	Appropriate	Appropriate	Successful single shock conversion, received ICD
9	Polymorphic VT	Initial presentation: syncope VT	Y	Acute MI	3	Appropriate	Appropriate	Successful single shock conversion, received ICD
10	Coarse VF/ polymorphic VT	Initial presentation: syncope VT	Y	Acute MI	3	Appropriate	Appropriate	Successful single shock conversion, received ICD
11	Monomorphic VT	Weakness and palpitations resulting in calling 911 VT	N	Nonischemic Cardiomyopathy	56	Appropriate	Appropriate	Successful single shock conversion, received ICD

CRT-D = cardiac resynchronization therapy – defibrillation; LBBB = left bundle branch block; LVEF = left ventricular ejection fraction; MI = myocardial infarction; N = no; P-WCD = patch-wearable cardioverter-defibrillator; SVT = supraventricular tachycardia; VF = ventricular fibrillation; Y = yes; other abbreviations as in Table 1.

therapies off in patients with active ICDs. There were 4 episodes of sustained VT/VF detected by the ICD but not detected by the WCD due to it not being worn.[27] Furthermore, as shock therapies were disabled in the ACE-DETECT study, it is unknown whether the ASSURE can deliver appropriate and successful shocks in the WCD intended-use population for the duration of real-world prescription lengths.

In this study, 8 successful and appropriate single shock conversions occurred in 6 symptomatic patients with sustained arrhythmias. Most of these patients were on amiodarone therapy; despite likely higher defibrillation thresholds due to antiarrhythmic drug use, they were successfully converted back to sinus rhythm with a single shock. Furthermore, there were no arrhythmic deaths due to the device not attempting to shock sustained arrhythmic events.

The high occurrence of successful conversions and the lack of arrhythmic deaths may be associated with the high daily wear compliance observed in the study. Patients in the ACE-DETECT study showed a high mean wear-time of 22.2 h/d, but the study only observed patients for 30 days.[27] Moreover, the first and last days of wear were excluded from wear-time calculations in the ACE-DETECT study, resulting in a lower eligibility period relative to actual wear time. Patients in the VEST demonstrated noncompliance with the LifeVest, resulting in failure to reach a significant improvement in arrhythmic death.[21] A subsequent per protocol analysis showed significant reduction in arrhythmic mortality in compliant patients.[28] These data suggest that compliance is related to the effectiveness of a WCD.

The current study shows a low false alarm and low inappropriate shock rate in addition to the effective detection and conversion of shockable events. In this study, 61.7% of patients experienced 0 false alarms/d, compared to only 28.3% patients experiencing 0 false alarms/d with the LifeVest.[29] The inappropriate shock rate observed was numerically lower and statistically similar to that reported in the VEST.[21] In ACE-DETECT, shock alarms and therapies were disabled.[27] Nevertheless, the investigators estimated an inappropriate shock rate of 0.00527 per subject-month, compared to a rate of 0.0036 per subject-month observed in the study.[30]

STUDY LIMITATIONS. First, this was a single-arm study, a design intended to avoid withholding life-saving therapy from patients at high risk of SCA. Second, several patients exited the study for reasons other than WCD no longer being indicated. However, the prescription length was extended in 27.2% of enrolled patients; of these, 9.5% of patients wore the P-WCD for more than 150% of their initial anticipated prescription length. By comparison, significant attrition was observed in the VEST in which all patients were enrolled for 90 days. The proportion of patients who wore the WCD on any given day decreased from 80.8% (95% CI: 78.8%-82.8%) immediately following randomization to 41.3% (95% CI: 37.5%-44.9%) at 90 days, and the average hours worn per day decreased from a mean of 16.3 ± 9.8 hours per day immediately following randomization to 8.3 ± 10.6 hours per day at 90 days.[21] In ACE-DETECT, study participation was limited to a short duration (30 days); therefore, follow-up was not long enough to adequately assess for attrition.

CONCLUSIONS

This study of a novel, water-resistant P-WCD met primary and secondary effectiveness and safety endpoints. There were no patient deaths or missed episodes requiring external rescue, and high patient compliance enabled a high number of successful life-saving conversions.

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APPENDIX For additional methods and tables, please see the online version of this paper.