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Data Article

An innovative 12-lead resting electrocardiogram dataset in professional football

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A B S T R A C T

This paper aims to provide a comprehensive and innovative 12-lead electrocardiogram (ECG) dataset tailored to understand the unique needs of professional football players. Other ECG datasets are available but collected from common people, normally with diseases confirmed, while it is well known that ECG characteristics change in athletes and elite players as a result of their intense long-term physical training. This initiative is part of a broader research project employing machine learning (ML) to analyse ECG data in this athlete population and explore them according to the International criteria for ECG interpretation in athletes. The dataset is generated through the establishment of a prospective observational cohort consisting of 54 male football players from La Liga, representing a UEFA Pro-level team.

Named the Pro-Football 12-lead Resting Electrocardiogram Database (PF12RED), it comprises 163 10-s ECG recordings, offering a detailed examination of the at-rest heart activity of professional football athletes. Data collection spans five phases over multiple seasons, including the 2018–2019 postseason, the 2019–20 preseason, the 2020–21 preseason, and the 2021–22 preseason. Athletes undergo medical evaluations

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that include a 10-s resting 12-lead ECG performed with General Electric's USB-CAM 14 module (https://co.services.gehealthcare.com/gehcstorefront/p/900995–002), with data saved using General Electric's CardioSoft V6.73 12SL V21 ECG Software. (https://www.gehealthcare.es/products/cardiosoft-v7)
The data collection adheres to ethical principles, with clearance granted by the Autonomous Community of Andalusia Ethics Committee (Spain) under protocol number 1573-N-19 in December 2019. Participants provide informed consent, and data sharing is permitted following anonymization. The study aligns with the Declaration of Helsinki and adheres to the recommendations of the International Committee of Medical Journal Editors (ICMJE).
The generated dataset serves as a valuable resource for research in sports cardiology and cardiac health. Its potential for reuse encompasses:

1. International Comparison: Enabling cross-regional comparisons of cardiac characteristics among elite football players, enriching international studies.
2. ML Model Development: Facilitating the development and refinement of machine learning models for arrhythmia detection, serving as a benchmark dataset.
3. Validation of Diagnostic Methods: Allowing the validation of automatic diagnostic methods, contributing to enhanced accuracy in detecting cardiac conditions.
4. Research in Sports Cardiology: Supporting future investigations into specific cardiac adaptations in elite athletes and their relation to cardiovascular health.
5. Reference for Athlete Protection Policies: Influencing athlete protection policies by providing data on cardiac health and suggesting guidelines for medical assessments.
6. Health Professionals Training: Serving as a training resource for health professionals interested in interpreting ECGs in sports contexts.
7. Tool and Application Development: Facilitating the development of tools and applications related to the visualization, simulation and analysis of ECG signals in athletes.

Specifications Table

Subject	Signal Processing, sports health, sports and exercise medical sciences.
Specific subject area	Evaluation of 10 s 12-lead electrocardiogram in sports cardiology.
Data format	Raw, XML, CSV/Excel, PDF
Type of data	Table, XML
Data collection	Resting in supine position, each participant's 12-lead electrocardiogram (ECG) was captured with General Electrics (GE) USB-CAM 14 for a duration of 10 s at 500 Hz using the GE CardioSoft software. Filtering processes were performed on the raw data helped by the ECG Visualizer software [1].

(*continued on next page*)

Data source location	The data were gathered from La Liga, Spain, from professional football players. For confidentiality reasons, the specific football team or geographical location is not disclosed in this study. Country: Spain
Data accessibility	Repository name: PF12RED - Pro-Football 12-lead Resting Electrocardiogram Database Direct URL to data: https://github.com/dradolfomunoz/PF12RED [2] Instructions for accessing these data: Access to the data is public and freely available to anyone with internet access and the dataset's web address.

1. Value of the Data

- Specialized Athlete ECG Database: This dataset addresses a critical gap by focusing on professional football players, offering unique insights into their cardiac activity during cardiological screenings at rest compared to the general population [3–7].
- Advancing Sports Cardiology: Researchers and practitioners in sports cardiology can utilize this dataset as a reference for understanding and diagnosing cardiac conditions specific to elite football athletes [8,9].
- Machine Learning Applications: The dataset, paired with the ECG Visualizer tool [1], provides a foundation for developing and testing machine learning models, potentially automating diagnostic processes for arrhythmias in athletes [10].
- Influencing Athlete Protection Policies: Sports organizations, including UEFA and FIFA, can benefit from this dataset to enhance pre-competitive health screenings and contribute to the formulation of athlete protection policies [11,12].
- Multicentric Studies: The dataset's innovative nature encourages collaboration, supporting multicentric studies and data sharing in various sports, promoting a comprehensive understanding of cardiac health in athletes.

2. Background

As the first public database of its kind, this innovative 12-lead resting electrocardiogram dataset in professional football was assembled to fill a gap in the availability of ECG data from professional athletes. The dataset endeavours to provide UEFA and FIFA with a fundamental resource related to professional players, potentially influencing forthcoming rules and protocols in the field of sports cardiology.

The dataset was designed as an evolving platform, its creation was guided by the limited but relevant literature, such as the works by Bohm et al. [9] and the consensus statement by Drezner et al. [8], which provide context for interpreting ECGs in athletes. The methodology for data collection adhered to UEFA's pre-participation screening recommendations [12], ensuring relevance and applicability to current sports health practices.

With its forthcoming expansion to encompass athletes of all genders, whether professional or not, the dataset is positioned to serve as a crucial resource for sports cardiology research and development, particularly in the areas of methodology and clinical practise. The dataset is unique and is undergoing analysis in an effort to make it available to the wider research community and organisations tasked with formulating health policies in the sports industry.

3. Data Description

The dataset described in this paper is available a Github repository. The repository comprises several files and folders (See Fig. 1):

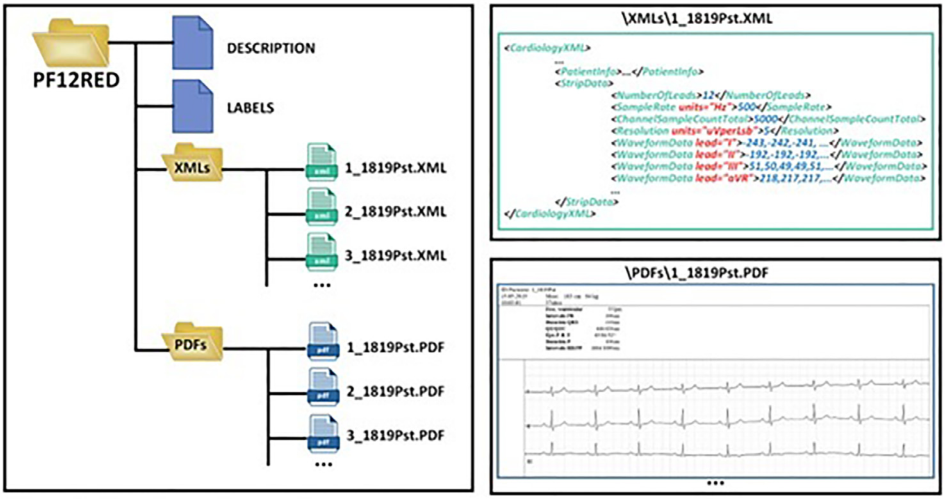

Fig. 1. The electronic repository structure.

The repository has an ordinated structure with a Readme.md archive, that contains a reference and brief explanation of the repository, and a License archive that provides details on the Creative Commons Legal Code and the CC0 1.0 Universal license utilised.

The “XML&PDF Table Description.xlsx” file, can also be found in the repository, and it includes a chronogram and details the type of data stored in each session. Yellow highlights indicate the XML and PDF references for each player.

“LabelData.xlsx” file is a table with critical electrocardiogram (ECG) data and descriptions of clinical labels for the 54 professional football players. The source of this data is lead "II." (See Tables 1 and 2)

“163XML” Folder: Contains individual anonymized XML files, each showcasing basic player data and raw 5000-block per lead for 10 s. The file naming format is 0_0000Xxx.XML, where ’0′ denotes the subject number, ’0000′ represents the season, and ’Xxx’ indicates whether the ECG was conducted at the beginning or end of the season.

“51_Individual_PDF” Folder: Similar to the 163XML Folder, follows the same naming structure. It includes reference ECGs in a PDF graphic format with two sheets presenting the 12 leads as commonly evaluated by medical professionals.

Fig. 2 illustrates a comparison between the ECG representation in PDF and XML in the ECG Visualizer.

4. Experimental Design, Materials and Methods

4.1. Data acquisition and processing

Participants: The data was gathered from 54 male La Liga UEFA Pro-level football players. The characteristics of the population are shown in Table 3.

Data Acquisition: The data was extracted with the Medical Stress Acquisition CAM-14 Module Kit from General Electric, which was connected to a personal computer that was operating the CardioSoft V6.73 12SL V21 software from General Electric. The ECGs were archived in both XML and PDF formats. Diagnostic data was exported to XML/Excel files from the local server. A CSV file was utilised to store the reference ECG selections for each participant.

Table 1
Extract and Distribution of recordings in LabelData.xlsx showing relevant findings in relation to International Criteria for ECG Interpretation [8]: Sinus Rhythm (SR), Sinus Bradycardia (SB), Incomplete Right Bundle Branch B (iRBBB), T Wave Inversion (TWI).

SR	SB	iRBBB	N	T Wave Inversion (TWI)											
				I	II	III	aVR	aVL	aVF	V1	V2	V3	V4	V5	V6
	X	X	**1**				X			X					
X			**2**				X								
	X	X	**3**				X			X					
	X		**4**				X								
	X		**5**				X			X					
X			**6**										X	X	X
X			**7**				X								
	X	X	**8**				X			X					
X		X	**9**			X	X			X					
	X		**10**				X								
	X		**11**				X			X					
X			**12**				X			X					
	X		**13**				X								
	X		**14**				X			X	X				
	X		**15**				X								
	X		**16**				X			X	X				
	X		**17**			X	X			X					
X			**18**				X			X					
	X		**19**							X					
X			**20**			X	X			X					
	X		**21**				X								
	X		**22**				X			X					
	X		**23**			X	X			X					
	X		**24**				X								
X			**25**				X			X					
	X	X	**26**				X			X					
X		X	**27**			X	X			X					
X			**28**				X			X					
X			**29**				X			X					
	X		**30**				X			X					
X			**31**				X			X					
	X		**32**				X			X					
X		X	**33**				X			X	X				
	X		**34**				X								
	X	X	**35**				X			X					
X			**36**												
	X		**37**				X			X					
X		X	**38**				X								
	X		**39**				X			X					
	X		**40**				X			X					
	X		**41**				X								
X			**42**				X								
	X		**43**				X			X					
	X		**44**				X			X					
	X		**45**				X								
	X	X	**46**				X			X					
	X		**47**				X			X					
X			**48**				X			X					
	X	X	**49**				X			X					
	X		**50**				X			X					
	X		**51**				X			X					
X			**52**							X	X	X	X	X	
X			**53**				X								
	X		**54**				X			X					
19	35	11	**N**	0	0	5	50	0	0	38	4	1	2	2	1
35,19	64,81	20,37	**% Total**	0,00	0,00	9,26	92,59	0,00	0,00	70,37	7,41	1,85	3,70	3,70	1,85

Table 2
Extract and Distribution of recordings in LabelData.xlsx showing relevant findings in relation to Age (years), Weigh (Kg), Heigh (cm), Race, SysBP (mmHg), DIABP (mmHg), Ventricularrate (bpm), PQInterval (ms), PQInterval (ms), QRSDuration (ms), QTInterval (ms), QTCInterval (ms), RRInterval (ms) and P and R Axis (°).

	Age (years)	Weight (Kg)	Height (cm)	Race	SysBP (mmHg)	DiaBP (mmHg)	Ventricular Rate (bpm)	PQInterval (ms)	QRSDuration (ms)	QTInterval (ms)	QTCInterval (ms)	RRInterval (ms)	PPInterval (ms)	Paxis (°)	RAxis (°)
1	**37**	**84**	**183**	Caucasian	105	70	55	196	110	448	428	1084	1090	65	84
2	**23**	**77**	**184**	Caucasian	107	75	62	280	92	414	420	960	965	36	82
3	**29**	**75**	**183**	Caucasian	105	70	55	158	110	432	413	1082	1090	44	88
4	**32**	**82**	**187**	Caucasian	123	83	47	152	100	430	380	1262	1275	−18	74
5	**35**	**72**	**184**	Caucasian	106	79	38	194	106	494	392	1590	1575	77	72
6	**32**	**77**	**181**	Latin	102	73	63	194	96	426	435	958	950	37	41
7	**24**	**76**	**184**	Caucasian	127	73	69	184	92	400	428	862	865	48	71
8	**28**	**77**	**180**	Caucasian	118	71	48	142	112	462	412	1250	1250	51	87
9	**31**	**64**	**171**	Caucasian	112	71	61	176	112	432	434	978	980	47	16
10	**35**	**74**	**182**	Caucasian	122	81	52	166	92	428	398	1144	1150	70	75
11	**26**	**74**	**185**	African	109	79	42	180	104	482	402	1444	1425	62	76
12	**21**	**75**	**178**	Caucasian	120	83	66	148	100	392	410	910	905	40	63
13	**28**	**75**	**178**	Caucasian	115	82	50	230	94	428	390	1196	1200	80	26
14	**35**	**82**	**188**	Latin	132	81	45	146	78	464	401	1348	1330	38	69
15	**30**	**74**	**182**	Caucasian	126	80	54	182	108	426	403	1112	1110	34	53
16	**23**	**68**	**170**	Caucasian	115	78	55	162	84	440	420	1084	1090	61	38
17	**23**	**67**	**178**	Caucasian	105	80	38	150	104	474	376	1592	1575	41	35
18	**30**	**79**	**186**	Latin	135	75	63	206	98	428	437	946	950	42	88
19	**20**	**70**	**172**	African	110	72	43	192	102	460	388	1396	1395	51	55
20	**22**	**80**	**177**	Latin	135	83	64	166	94	432	445	940	935	55	90
21	**34**	**70**	**168**	Caucasian	115	70	48	210	86	440	393	1242	1250	37	12
22	**30**	**88**	**189**	Caucasian	126	78	49	154	112	430	388	1234	1220	41	70
23	**33**	**88**	**190**	Caucasian	115	71	47	126	108	460	407	1278	1275	75	84
24	**30**	**79**	**185**	Caucasian	133	83	39	202	102	480	386	1530	1535	18	56
25	**23**	**70**	**177**	Caucasian	128	66	69	152	102	396	424	864	865	57	74
26	**23**	**63**	**169**	Latin	117	76	58	178	110	416	408	1028	1030	43	63
27	**22**	**82,5**	**192**	Caucasian	121	81	63	150	108	386	395	956	950	69	60
28	**23**	**76**	**182**	Latin	124	76	73	154	104	374	412	816	820	72	80

(*continued on next page*)

Table 2 (*continued*)

	Age (years)	Weight (Kg)	Height (cm)	Race	SysBP (mmHg)	DiaBP (mmHg)	Ventricular Rate (bpm)	PQInterval (ms)	QRSDuration (ms)	QTInterval (ms)	QTCInterval (ms)	RRInterval (ms)	PPInterval (ms)	Paxis (°)	RAxis (°)
29	**33**	**85**	**190**	Caucasian	112	80	63	110	104	426	435	958	950	42	45
30	**27**	**65**	**170**	Caucasian	120	80	56	130	98	420	405	1078	1070	70	70
31	**21**	**72**	**176**	Caucasian	113	85	77	164	96	390	441	780	775	67	63
32	**22**	**73**	**180**	Caucasian	109	75	51	124	96	422	388	1166	1175	103	90
33	**22**	**75**	**181**	Caucasian	128	69	64	160	120	410	422	930	935	68	−24
34	**28**	**65**	**171**	Caucasian	127	68	53	144	90	426	399	1122	1130	69	70
35	**19**	**62**	**172**	Caucasian	122	79	51	124	112	442	407	1166	1175	35	77
36	**21**	**80**	**180**	Caucasian	115	79	95	154	104	376	472	628	630	72	75
37	**20**	**81**	**191**	Caucasian	111	81	56	162	104	470	453	1072	1070	75	93
38	**18**	**85**	**190**	Caucasian	128	85	65	132	110	412	428	918	920	74	59
39	**26**	**70,5**	**175**	Caucasian	118	70	46	140	106	464	406	1298	1300	72	69
40	**24**	**79,3**	**185**	African	113	81	50	162	98	436	397	1196	1200	6	68
41	**22**	**74**	**175**	Caucasian	128	82	46	164	94	426	372	1316	1300	70	100
42	**24**	**64**	**167**	Caucasian	107	74	60	164	104	414	414	1000	1000	58	82
43	**25**	**68,6**	**174**	Caucasian	101	85	59	172	100	422	417	1020	1015	63	95
44	**22**	**68**	**175**	Caucasian	129	76	55	170	96	416	397	1098	1090	60	62
45	**25**	**75**	**188**	African	127	84	53	164	108	424	397	1132	1130	7	65
46	**19**	**60**	**170**	Asian	106	78	54	146	120	466	441	1120	1110	48	59
47	**31**	**73**	**180**	Caucasian	115	77	46	176	94	436	381	1294	1300	57	82
48	**19**	**83**	**190**	Caucasian	115	76	65	336	102	386	401	926	920	26	100
49	**24**	**76**	**182**	Caucasian	106	79	58	196	114	420	412	1026	1030	48	54
50	**18**	**77**	**186**	African	128	84	42	250	106	462	385	1440	1425	31	83
51	**21**	**79**	**185**	Caucasian	109	72	45	186	94	414	358	1348	1330	77	84
52	**29**	**75**	**176**	African	107	79	67	192	104	464	490	902	895	48	63
53	**29**	**86**	**189**	Latin	128	79	70	170	92	388	419	858	855	61	72
54	**19**	**75**	**190**	Caucasian	106	75	58	150	90	418	410	1032	1030	32	97
	Age	**Weight**	**Height**	**Race**	**SysBP**	**DiaBP**	**Ventricular Rate**	**PQInterval**	**QRSDuration**	**QTInterval**	**QTCInterval**	**RRInterval**	**PPInterval**	**PAxis**	**RAxis**
Average	25,74	74,91	180,61		9,86	5,02	9,60	38,71	8,01	28,08	23,00	192,04	191,01	25,21	25,08
SD	5,16	6,78	6,92		118,45	77,18	54,33	169,98	101,32	434,01	408,85	1.136,43	1.129,32	52,09	67,63

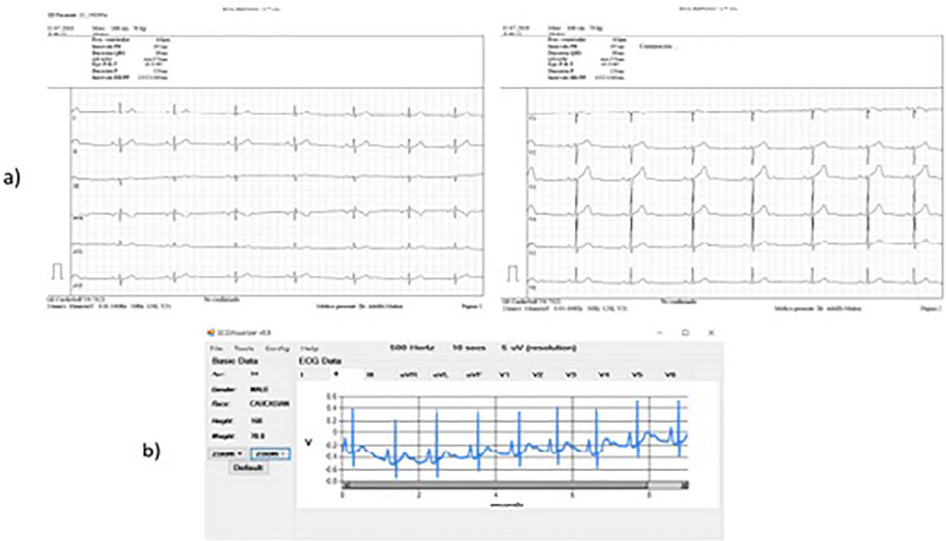

Fig. 2. a) Excerpt of 10-s 12-lead ECG in PDF format. b) Excerpt of 10-s "II" lead in ECG Visualizer from xml format.

Table 3
Population characteristics.

	Age (y)	Height (cm)	Weight (Kg)
Average	25.74	180.61	74.90
±SD	5.16	6.92	6.78

Procedure: Prospective observational cohort across five phases: 2018–2019 postseason, 2019–20 preseason, 2019–20 postseason, 2020–21 preseason, and 2021–22 preseason was performed.

An annual average of 25–30 players composes a professional football squad. Cardiovascular screening is a requirement outlined in the regulations of UEFA [12]. A 10-second, 12-lead electrocardiogram (ECG) was obtained during the data collecting process using the GE Medical Stress Acquisition CAM-14 Module Kit in conjunction with General Electric's CardioSoft V6.73 12SL V21 software. Also included in the sample are end-of-season electrocardiograms.

The cardiological screening was developed as follows:

(1) The players arrived at the medical center and read and signed the informed consent for the cardiological screening and the research project.
(2) In the supine position on a table the electrodes corresponding to the 12 leads were connected to the athlete.
(3) USB-CAM 14 was connected to the 12 leads.
(4) Cardiosoft software started the data acquisition at 500 Hz in a continuous form.
(5) AAMM as a Sport and Exercise physician, selected the proper 10-s ECG.
(6) The data acquisition was stopped.

Data Validation, Labelling and Characterization: The cardiological screening was the responsibility of the principal investigator, AAMM, a qualified sport and exercise physician with expertise in sports cardiology. As such, he inspected the acquisition of each ECG and XML, manually labelled features, and results in person. Every ECG and PDF report underwent a data validation check. The GE ECG Software was utilised to store the final diagnosis, and a resume CSV file was posted to the repository. https://github.com/dradolfomunoz/PF12RED.

For the purpose of validating the data and enabling free-to-use software to extract and display the ECG, the second author MJDM created the ECG Visualizer Tool, which also performed data translation and CSV format conversion. [1] https://github.Com/Mjdominguez/ECGVisualizer. This tool permitted to apply of different *filtering methods* as fixed window average, sliding window average, sliding window median, and band rejection filter.

Also, a *noise reduction* process like the sequential noise reduction method is applied to raw ECG data to address power line interference, electrode contact noise, motion artefacts, muscle contraction, and baseline noise. Finally, signal *filtering and peak detection* were used for signal filtering, eliminating noise, and automatically detecting P, Q, R, S, and T peaks. Four types of filtering: fixed window average, sliding window average, sliding window median, and band rejection filter.

To develop characterization and possible initial uses of the dataset, Machine Learning Development was done with the ECG Visualizer's reports for developing three classifiers: Random Forest, Support Vector Machine, and Artificial Neural Network. Hold-Out technique was applied with a 70–30 division for training and testing subsets and ML Classifiers were used:

- Random Forest: 10 estimators, unlimited maximum features.
- Support Vector Machine: Parameters obtained from the optimization process.
- Artificial Neural Network: Multilayer perceptron network with specific hyperparameters.

Limitations

The proposed dataset has certain limitations. Firstly, the data collection was conducted during typical seasons, posing challenges in organizing comprehensive data. The dataset might lack diversity due to limitations in the availability of individuals of different genders and ages. Despite efforts to seek more diversity, this constraint may affect the generalizability of the findings of studies based on our dataset. Additionally, we acknowledge missing data and potential loss of follow-up, impacting the overall completeness of the dataset. While these limitations don't negate the dataset's significance, they highlight considerations for researchers interpreting and utilizing the data for further investigations.

Ethics Statement

The data collection in this study involved human subjects. Relevant informed consent was obtained from the subjects. Ethical committee approval was obtained from the Autonomous Community of Andalusia Ethics Committee (Spain), with protocol number 1573-N-19. The study aligned with the Declaration of Helsinki and adheres to the recommendations of the International Committee of Medical Journal Editors (ICMJE).

Data Availability

Pro-Football 12-lead Resting Electrocardiogram Database (PF12RED) (Original data) (Github.com).

CRediT Author Statement

Adolfo Antonio Munoz-Macho: Conceptualization, Methodology, Investigation, Resources, Data curation, Writing – original draft; **Manuel Jesus Dominguez-Morales:** Software, Formal analysis, Resources, Validation, Writing – review & editing; **Jose Luis Sevillano-Ramos:** Supervision, Writing – review & editing.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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