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A conceptual model for understanding the zoonotic cutaneous leishmaniasis transmission risk in the Moroccan pre-Saharan area

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ABSTRACT

Leishmanioses are of public health concern in Morocco, mainly the Zoonotic Cutaneous Leishmaniasis (ZCL) endemic in the Moroccan pre-Saharian area. Transmission of this disease depends on eco-epidemiological and socio-economic conditions. Therefore, a multivariable approach is required to delineate the risk and intensity of transmission. This will help outline main disease risk factors and understand interactions between all underlying factors acting on disease transmission at a local and regional scale. In this context, we propose a new conceptual model, the Biophysical-Drivers-Response-Zoonotic Cutaneous Leishmaniasis (BDRZCL), adapted to the Pre-Saharian area. The proposed model highlights how the physical and human drivers affect the environment and human health. The incidence of ZCL is linked to human activity and biophysical changes or by their interactions. The human response added to risk drivers are the main components that influence the biophysical part. This model improves our understanding of the cause-effect interactions and helps decision-makers and stakeholders react appropriately.

1. Introduction

Leishmaniases are vector-borne diseases caused by protozoan parasites of the genus *Leishmania,* which phlebotomine sand flies transmit. Leishmaniases are endemic in 98 countries from four continents (Alvar et al., 2012), and one billion people are at risk of infection (Wamai et al., 2020). Depending on the eco-epidemiological conditions (biotic and abiotic conditions, parasite, vector, and host species), transmission cycles can be sylvatic or domestic (Carreira et al., 2014). In Morocco, cutaneous leishmaniasis is caused mainly by *L. major* and *L. tropica, and sometimes* by L. *infantum* whilevisceral leishmaniasis is caused by L. *infantum* (Rhajaoui, 2011;

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Kholoud et al., 2020).

ZCL caused by L. *major* is concentrated in pre-Saharan with Saharan biotopes being present in villages along the palm groves in the rural area (Bounoua et al., 2013; Kholoud et al., 2018). In these biotopes, the transmission intensity is under socio-economic and environmental conditions (Karmaoui et al., 2021a). Indeed, ZCL incidence is high in rural areas where the central economic sector is agriculture and livestock. In addition, local communities typically live in poor hygiene conditions and low health services in these rural areas. Therefore, a conceptual framework is required to delineate main disease risk factors and understand their interactions.

Information on the interaction between complex factors affecting human health would guide decision-makers. A valuable conceptual model would help in understanding disease transmission in a global view. These conceptual models are tools needed to manage disease transmission risk. Since vector-borne diseases such as ZCL are often associated with socio-economic and environmental changes, urbanization, agriculture, and biotope alterations, they would benefit from these conceptual models.

2. Material and methods

2.1. Study area

In this geographic area, most of the pre-Saharan region's Moroccan oases are present in four provinces: Errachidia, Ouarzazate, Zagora, and Tata (Fig. 1). This region's climate is arid, and the economic sector is based mainly on familial agriculture concentrated along the Wadi (temporary rivers) (Karmaoui and Balica, 2021b).

The study area extends over127720 km^2. The population is about one million and a half (4.3% of the national population), with a low density of 11.37% against 47% at the national scale (HCP, 2014).

In this region, ZCL is caused by *Leishmania major* and transmitted by the sandfly *Phlebotomus papatasi,* and *Meriones shawi* and *Psammomys obesus* are the reservoirs (Boussaa et al., 2010; Kehoe, 2017).

These provinces have experienced one to two peak outbreaks incidence between 2000 and 2015 (see Fig. 2) (the most extended documented period). Two epidemic outbreaks peaks were recorded in 2003 and 2010 in the Ouarzazate province and increased from 2005 to 2010 for Zagora and Errachdia.

2.2. Methodology

The construction of the conceptual model was based on the recommendation and definition of Earp and Ennett (1991), which refers to "a diagram of proposed causal linkages among a set of concepts believed to be related to a particular public health problem". Defined keywords, zoonotic cutaneous leishmaniasis (and ZCL), *L. major*, and vector-borne-disease, were used to search on Plos, Science Direct, Wiley, and Google Scholar. Information extracted was adapted to the ecologic and socio-economic conditions of the pre-Saharan biotope. A total of 29 papers published from 1986 to 2018 and focusing on climate variables, health, biology, human response, and environmental conditions, were selected. This model was based on the closest framework: Cutaneous Leishmaniasis Vulnerability Index including Anthropogenic, Geographical, Socio-economical, Services category, and Health components (Karmaoui, 2018), and the Local ZCL Vulnerability Index (components: Socio-economical, climatic, hydraulic, vegetation, and health) (Karmaoui and Zerouali, 2018).

Interactions between these components allowed to explore risk factors dynamics through the Driving Force - Pressure - State - Impact – Response (DPSIR) model that was adopted by the European Environment Agency (EEA). This model was adapted to consider the ZCL biological cycle in the context of the area. Components of the model were identified along with their associated variables.

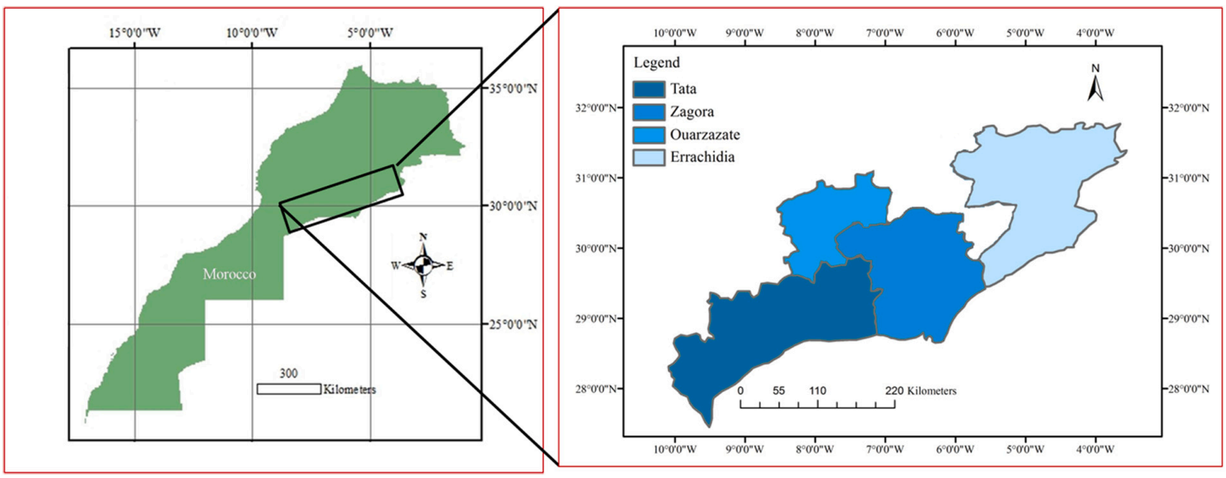

Fig. 1. Study area, the pre-Saharn provinces, Tata, Zagora, Ouarzazate, and Errachidia.

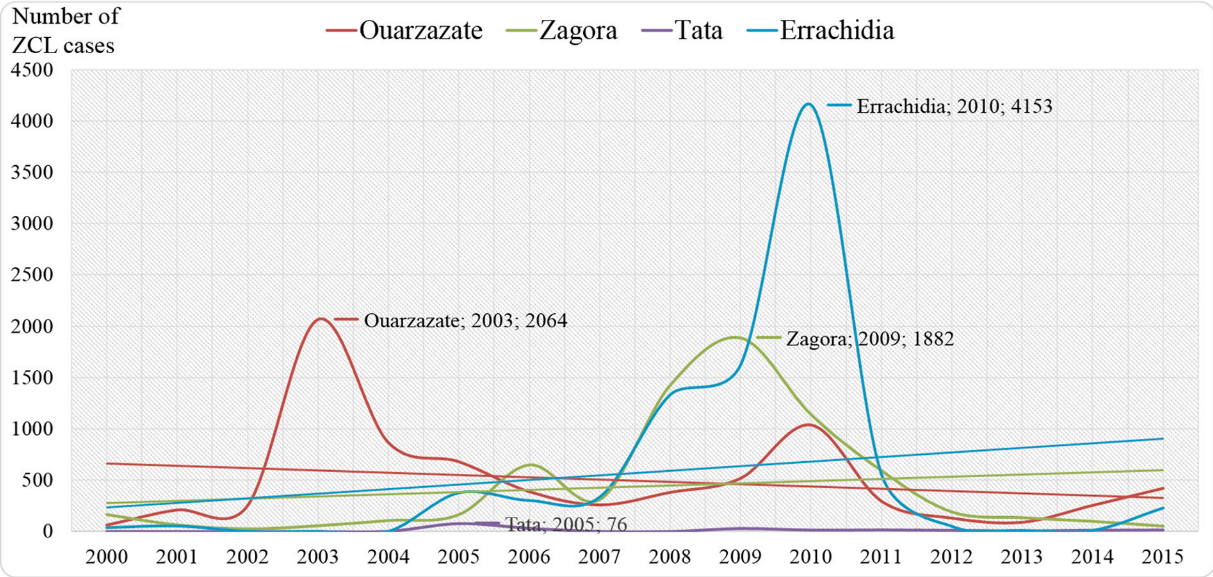

Fig. 2. Trends in ZCL cases in foci provinces in the Pre-Sahara. Straight lines represent the statistical trend in disease cases. Data source: Archives of the Moroccan health ministry from 2000 to 2015.

3. Results

Information on ZCL was extracted and classified into six sub-components Biotope, Biocycle, Density cases, Response, Physical, and Anthropogenic (human activity). Essential features linked to the disease were selected, including biophysical aspects of the parasite, vector, host, and reservoir host; climatic, vegetation, extreme events drivers, and human reactions. Reports on the occurrence of the oriental button (Leishmaniasis) in High Guir (South) dates back to 1914 in Morocco (Foley et al., 1914). The insect vector (*P. papatasi*) was identified in 1916 (Delanoë, 1916). Later, Leblanc reported the "oriental button" cases in Figuig (Leblanc, 1925). The first extensive study on phlebotomine was performed in 1947 by Gaud (1947). In 1970, it was depicted leishmaniasis' clinical diversity and their association with L. *major*, L. *tropica* or *L. infantum* (Rioux, 2001). In 1971, Bailly-Choumara et al. (1971) studied the spatio-temporal distribution of phlebotomine sandflies of Morocco in relation to bioclimatic conditions. In 1977, with the ban on the use of DDT to combat malaria transmission by anopheline vectors, ZCL had re-emerged as a public health concern (Boussaa, 2008). In 1997 a control program for cutaneous leishmaniasis was established in Morocco (PLCL, 2016), and in 1999, the first Iso-enzymatic and genetic study was performed (Benabdennbi et al., 1999). Later, Guernaoui (2000) reported of the presence of vector species in Marrakech: *P. papatasi,* (proven vector of L. *major) Phlebotomus sergenti* (proven vector of L. *tropica),* and *P. Longicuspis* (vector of L. *infantum*). In addition, the forecast concept for the distribution of leishmaniasis concerning climate change was introduced (Rioux and De La Rocque, 2003). A World Health Organization (WHO) consultation on the leishmaniasis control program took place in 2009 (PLCL, 2016).

We designed a Biophysical-Drivers-Response-ZCL (BDRZCL) framework with the information gathered. The eco-epidemiological conditions of ZCL at local and regional scales and their combinations in a socio-ecological system are the novel pieces added by the proposed conceptual model. The proposed model includes three components (Table 1).

- The biophysical component includes community structure (biotope), and ecosystem function (parasite, vector, host, and reservoir host)
- The drivers represent likely changes in climate, minimum and maximum temperatures, precipitation, humidity, vegetation density, heat waves, severe storms, floods, or drought.
- The response gathers all aspects of human actions and reactions, like surveillance, preparedness, and vector control.

Using existing literature (Table 1), a conceptual model (Fig. 3) was traced in relation to the impacts and response to ZCL. This model explored the trade-off between socio-economic and biophysical components at two geographic scales (regional and local) (Fig. 3). The incidence of ZCL is linked to human activity and biophysical changes or their interactions. The human response added to risk drivers are the main components that influence the biophysical part. In this conceptual model, the climatic and human drivers are the main risk factors of ZCL at regional and local scales. There are three main components (biophysical, drivers, and human response) specific to the oasis system, but they can be adapted for other ecosystems.

The main drivers are climatic and anthropogenic factors; they act on the three biotopes and the biological developmental cycle of reservoir hosts, vectors, and parasites. The reservoir, vector, and parasite co-existence in favorable conditions increase the incidence

Table 1
Main components and potential and possible indicators related to ZCL caused by L. *major*.

Scale	Component	Sub-component	Indicator	Brief descriptions	Reference
			Biotope	Presence of insect vector found in houses, caves, and shelters	Guernaoui and Boumezzough, 2009 and Guernaoui et al., 2010
			Urban	Increasing cases of ZCL in urban areas	Salah et al., 2007
Regional-scale		Biotope	Peri-urban	Presence of ZCL in peri-urban areas	Neouimine, 1996 Kahime et al., 2014
			Rural	Presence of insect vectors in various habitats in rural sites ZCL is endemic in rural sites	Guernaoui et al., 2005 Salah et al., 2007
			Domestic	Intra-domiciliary transmission	Lainson and Rangel, 2005
			Sylvatic	Ancient sylvatic cycle Reservoir hosts for L. *major* are sylvatic	Carreira et al., 2014 WHO, 2007
	Biophysical		Reservoir host	Identified reservoir hosts are *Meriones shawi* and *Psammomys obesus*	WHO, 2007
		Biocycle	Vector	*Phlebotomus papatasi* is the proven vector of ZCL An increase in vector abundance can increase the incidence of leishmaniasis	Bounoua et al., 2013 WHO, 2007 Gage et al., 2008 Karmaoui, 2020
Local-scale			Parasite	The agent of ZCL is the protozoan parasite L. *major*	Reithinger et al., 2001
		Density cases	Repartition Number of cases	The followings variables affect directly or indirectly the incidence and occurrence of ZCL cases: Surveillance (Gage et al., 2008), Preparedness (Kotnik and Ivović, 2017), Vector control (Faraj and Lake, 2015), Changes in climate (Rodhain, 2000), Surface climate variables (Bounoua et al., 2013), Aridity (Rioux et al., 1986), Hygiene (Kahime et al., 2014).	
			Surveillance	Detection of infections by L. *major* and other *Leishmania* species As a warning system element of adaptation Use to detect rodents/reservoir hosts	Gage et al., 2008 Bounoua et al., 2013
	Response (POLICY)	Response	Preparedness	Basic preparedness and rapid response mechanisms must be taken	Kotnik and Ivović, 2017
			Vector control	Measure to decrease the incidence of cutaneous leishmaniasis An increase in vector abundance can be due to the cessation vector control	Faraj and Lake, 2015 Maroli et al., 2013
			Changes in climate	Climate changes can drive the abundance and expansion of ZCL	Rodhain, 2000; Toumi et al., 2012
			Surface climate variables	ZCL is affected by surface climatic variables	Bounoua et al., 2013
			Precipitation	A rise in precipitation boosts vegetation, which favours proliferation of reservoir hosts and vector.	Yates et al., 2002 Faulde et al., 2008
Regional-scale			Minimum temperature	A rise in minimum temperature decreases the maturation time of the vector.	Kasap and Alten, 2006
			Maximum temperatures	Seasonal changes in minimal and maximal temperatures impact the ZCL cases	Faulde et al., 2008
			Water availability	Dams affect the soil temperature and humidity, impacting the vegetation cover, consequently changing sand fly and reservoir hosts abundances.	IPCC, 2014
		Physical	Altitude	The vector of ZCL is abundant in altitudes ranging from 400 to 800 Metres above sea level.	Boussaa et al., 2010
	Drivers		Vegetation	A rise in vegetation supports both reservoir hosts and vectors	Bounoua et al., 2013 Yates et al., 2002
			Warming and drought	Longtime warming and drought decrease the ZCL vector capacity	Bounoua et al., 2013
			Humidity	A rise in humidity decreases the maturation time of the vector.	Kasap and Alten, 2006
			Aridity	Cutaneous leishmaniasis occurs almost exclusively in arid Saharan regions The vector of ZCL *papatasi* is abundant in arid climatic conditions	Rioux et al., 1986 Marty et al., 1989 Bounoua et al., 2013
			Socio-ecological conditions	The incidence of ZCL is localized in the oasis agro-system, where the ecological and socio-economic conditions are weak	Kahime et al., 2014
Local-scale		Anthropogenic (human activity)	Hygiene	The incidence of ZCL is associated with low hygiene	Kahime et al., 2014
			Environmental change	The building of dams change the soil temperature and humidity, impacting the vegetation cover and affecting the abundance of sandflies and rodents (reservoir).	IPCC, 2014
					Desjeux, 2001

(*continued on next page*)

Table 1 (*continued*)

Scale	Component	Sub-component	Indicator	Brief descriptions	Reference
			Human intervention	Anthropogenic factors (deforestation, new settlements, the building of dams…) accelerate the emergence of ZCL	
			Urbanization	Globally, urbanization is considered a risk factor for leishmaniasis	Desjeux, 1999
				P. papatasi persists and resists after the urbanization phenomena	Boussaa, 2008
			Soil construction	Vectors are frequent in areas where the houses are built using clay	Guernaoui, 2006

ZCL, Zoonotic Cutaneous Leishmaniasis.

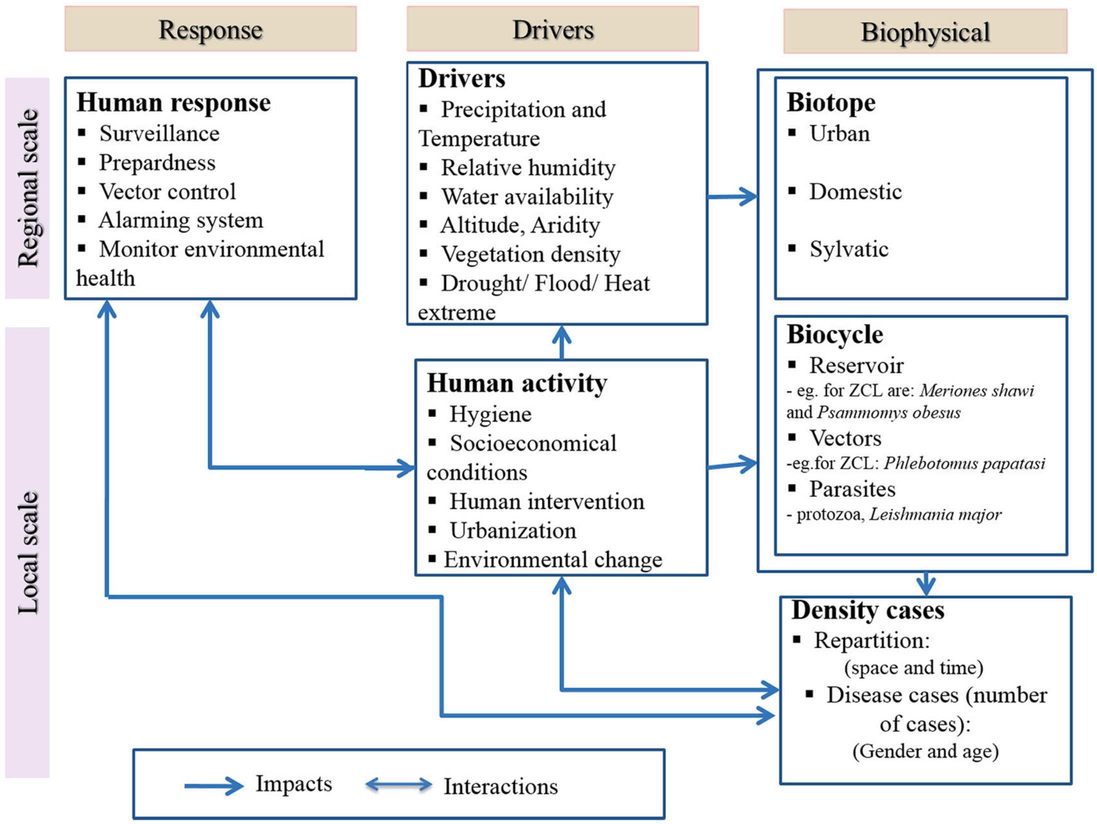

Fig. 3. Schematic representation of the proposed Biophysical-Drivers-Response-Zoonotic Cutaneous Leishmaniasis framework of ZCL transmission and humans response in Moroccan oases.

rate. This can be impacted by human activities like land use (forestation and deforestation) and environmental and personal hygiene. On the other hand, the water availability maintains a necessary vegetation cover that supports high biodiversity favoring the establishment of the developmental parasite cycle that impacts ZCL incidence. This influences the human response and accelerates or stops the land use (at the local scale) and the physical drivers, especially the climatic drivers such as precipitation, temperature, and relative humidity at the regional scale.

4. Discussion

A large amount of literature on environmental science concerns transmission risk factors (variables) of ZCL caused by L. *major*. The variables studied were: latitude and season (Abonnenc, 1972), urbanization (Desjeux, 1999), bioclimate (Rispail et al., 2002), precipitation and vegetation density (Yates et al., 2002), soil construction (Guernaoui, 2006), reservoir (WHO, 2007), biotope (Guernaoui and Boumezzough, 2009 and Guernaoui et al., 2010), altitude (Boussaa et al., 2010), temperature, moisture, and wind (Boudrissa et al., 2012; Rioux, 2006), aridity and surface climate variables (Bounoua et al., 2013) and socio-ecological conditions (Karmaoui, 2018). The proposed model aimed at exploring the interaction between these factors in the context of climate change. It is the first attempt to visualize these interactions in the context of ZCL in the Pre-Saharan region.

Several models that include environmental and health components have been developed. The Burden of Disease (BoD) was recommended in the 1990s by the World Bank to estimate health loss due to risk factors (Murray and Lopez, 1996 & Jamison and Jardel, 1994). Others are the Driving Force - Pressure - State - Impact – Response (DPSIR) (Rapport and Friend, 1979), Millennium Ecosystem Assessment (MEA) (Corvalan et al., 2005), Environmental Public Health Indicators (EPHI) (developed by The United States Centers for Disease Control and Prevention based on the work of Thacker et al. (1996), Multiple Exposure-Multiple Effect (MEME) (WHO, 2004), the causal web (a diagram that is created to link causes and effects), and the Driving force-Pressure-State-Exposure-Effect-Action (DPSEEA). The latter allows for assessing risk for contaminants (Von Schirnding, 2002). It gathers professionals, practitioners, and managers of public health environmental fields (Waheed et al., 2009). Several specific frameworks based on or derived from DPSIR facilitate our understanding of the social-ecological system. To our knowledge, no model is dealing with the ZCL at the North African scale. For cutaneous leishmaniasis, the closest framework developed is the "Strategic framework for leishmaniasis control in the WHO European Region 2014–2020" (Ejov and Dagne, 2014), that outlines the following objectives and actions: Capacity-building (guidelines developed and published and public health staff trained), Surveillance (information systems, collect and analyze data), health education, Case management, outbreak preparedness and response, Control of sand-fly vectors and reservoir hosts, community participation, Evaluation (the impact of measures applied), Environmental management and personal protection (modification of the habitats, local environmental effects, and conflicts), operational researchand intersectoral collaboration.

In Morocco, an epidemiological model that includes risk factors using a vertical analysis to emphasize possible critical interventions has been proposed (Laboudi *et al.,* 2018). This study argues that community involvement is essential for improving integrated vector management control (IVMC). It also considers the inter-sectoral strategy framework (using insecticide and rodents control) instead of medical treatments. At the national scale, a leishmaniasis control program (PLCL, 2016) called "2010-2012 Strategic Response Plan" was established to reduce the incidence of cutaneous leishmaniasis caused by L. *major* and L. *tropica*. According to PLCL, the reduction of ZCL cases registered at the national level was 88.5%, with the highest reduction (98.6%) recorded in Errachidia (a study area site) with 4128 cases in 2010 and 57 cases in 2012. In addition, PLCL included another plan, the strategic action plan for the fight against leishmaniasis 2013-2016.

5. Conclusion

The multidimensional aspect of the disease requires a multivariable approach to demonstrate how the physical and human drivers affect the environment and then human health. In this context, a new conceptual model, the Biophysical-Drivers-Response-ZCL (BDRZCL), was operationalized in the case Pre-Saharan area. Therefore, the proposed conceptual model helps delineate interactions (associations) of risk factors involved in ZCL transmission in the pre-Saharan region of Morocco.

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Ethics approval

We further confirm that any aspect of the work covered in this manuscript that has involved human patients has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript.

Declaration of Competing Interest

I declare no competing interests exist.

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