Patterns and Humans

Niklas Manz and Flavio H. Fenton

Abstract The appearance of spiral structures on the human tongue (geographic tongue) and skin (pathological rashes) are described. Affected and often migrating areas on the tongue can be bistable, patch-like fronts or waves. Pathological rashes with an expanding region of redness is often a result of an autoimmune disease in which the human immune system becomes hyperactive and attacks healthy tissues. In addition, we show a rotating spiral created by humans, which has been described as a reaction-diffusion waves in an excitable medium.

1 Introduction

Nonlinear dynamical systems far from thermodynamic equilibrium reveal a fascinating wealth of spatial, temporal, and spatiotemporal structures on a macroscopic scale in various physical, chemical, and biological pattern-forming systems. And even within one field, for example biological systems, a wide variety of patterns can be observed. Here, we mention a few large scale organizations as, for example, population patterns (e.g., grey squirrels in Britain [1]), vegetation distributions (e.g., fairy circles [2]), the dynamics of living cells (e.g., cellular slime molds (see chapter **Spiral Waves of the Chemo-attractant cAMP Organise Multicellular Development in the Social Amoebae**) or bacterial colonies [3]), and epidemics (e.g., rabies in foxes [4], black death epidemic (1347–1351) in Europe [5], or the bubonic plague in China [6]).

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On a smaller scale and within the human body, we can observe electrical depolarization waves on the heart (see chapter **Spiral Waves in the Heart**), the brain (see **Yet More Spirals**), or excitation waves during labour in the uterus [7], and on the tongue [8].

In this chapter, we will focus on spatiotemporal spiral-like structures (see chapter **Chemical Oscillations and Spiral Waves**) on and with humans. The tongue and the skin can exhibit patterns of propagating fronts, a steady state change in a *bistable system* (two stable and one unstable fixed point between the two basins of attraction) or wave like structures as in an *excitable system* (one stable fixed point in the phase space: see **Generation of Spirals in Excitable Media**). The last section describes a spiral performed by humans.

2 Patterns on the Tongue

The tongue is primarily a muscle necessary for speaking and moving food for chewing and swallowing with a thin, upper layer, the *epithelium* which consists of a mucous membrane with small nodules of tissue. There are four types of these, *lingual papillae* called tiny, pinkish-white bumbs containing hair-like structures ($d \approx 35$ μm, $l \approx 250$ μm). One of these, the *filiform papillae* do not contain taste buds and are located in the front two-thirds of the tongue.

The mucous membrane of the human tongue, as of many animals, is susceptible to a wide variety of diseases, which is of interest for the field of nonlinear dynamics [9]. One example is the *inflammatory psoriasiform mucositis* of *filiform papillae* with smooth, red areas and often slightly raised, grayish white borders. Because of the sometimes map-like appearance of affected areas it is called *Geographic Tongue* (GT). Other medical terms for these patterns are, for example, *lingua geographica*, *benign migratory glossitis*, and *erythema migrans lingualis*. GT is painless but some patients report numbness and tingling of the affected areas. It can be found in (1–4)% of the population [10].

The first reports of GT were published by Rayer in 1831 [11], but the underlying mechanisms for the inflammatory reaction are still unknown. It appears at higher percentages in, for example, females than males [12] or children than adults [10]. Race/ethnicity affects its appearance, but numbers vary in publications. Genetic predisposition seems also to be responsible. Liang et al. report a significant correlation of GT with mutations in the Interleukin-36 receptor antagonist (*IL36RN*) gene [13], which has previously been shown to cause inflammatory skin diseases.

Several GT-associated health conditions have been reported, as, for example, allergies, diabetes, generalized pustular psoriasis (a chronic skin condition caused by an overactive immune system), fissured tongue (cracks, grooves, or clefts appear on the top and sides of the tongue), asthma, hormonal disturbances, juvenile diabetes, stress, and Down syndrome. External factors such as stress, vitamin deficiency, spicy and/or acidic food, and toothpaste with additives, whitening agents, or heavy flavoring have also been reported to increase the probability to have GT, whereas smoking has been reported to have an inverse association [14].

Fig. 1 Tongue with three different structures: Bistable, patchy front (upper left), elongated 'target pattern' (front), and elongated spiral with the tip at the left lateral of the tongue (copyright: Martin Spiller, http://doctorspiller.com/geographic-tongue)

Fig. 2 Multiple logarithmic spiral structures appearing at the front of a tongue (Wikimedia common, created by Martanopue; CC BY-SA 3.0)

Because GT is not an infection, it cannot be transmitted (entirely benign), and there is no curative treatment. To minimize flare-ups, patients can use anti-inflammatory medication, mouth rinse with anesthetics, zinc supplements, topically applied steroids, and generally avoiding tobacco, nuts, and spicy/acidic food.

The affected, often migrating areas can be simply bistable, patch-like fronts (see upper left structure in Fig. 1) but can also appear as waves. Due to the anisotropic structure of the tongue, circular target pattern or real Archimedean spirals are unlikely. Therefore, elongated, elliptical 'target pattern' (small elliptical structure closer to the tip) or spirals (large structure on the side) can be found. More logarithmic appearing spirals have also been observed (see Fig. 2).

Patients with GT seem to display a tremendous variation in appearance and evolution of their tongue patterns. This includes (i) severity, the total number of lesions and their extent on the surface of the tongue; (ii) frequency of lesional formation, as some patients are never without lesions, while other have lesions very sporadically; and (iii) rapidity of the lesional evolution as some patients state that they can watch their tongues change and patterns enlarge from hour to hour, while other patients have lesions that do not change at all.

To date, only one publication has linked GT to a reaction-diffusion (RD) system [8]. Seiden and Curland simulated GT as an excitable medium using an anisotropic cellular automaton model (see chapter **A Lattice-Gas Cellular Automaton Model for Discrete Excitable Media**) and were able to reproduce the 'elongated' patches and predict the appearance of spirals. However, their generic model had no link to any physiological parameter and could not be used to gain any insights into GT.

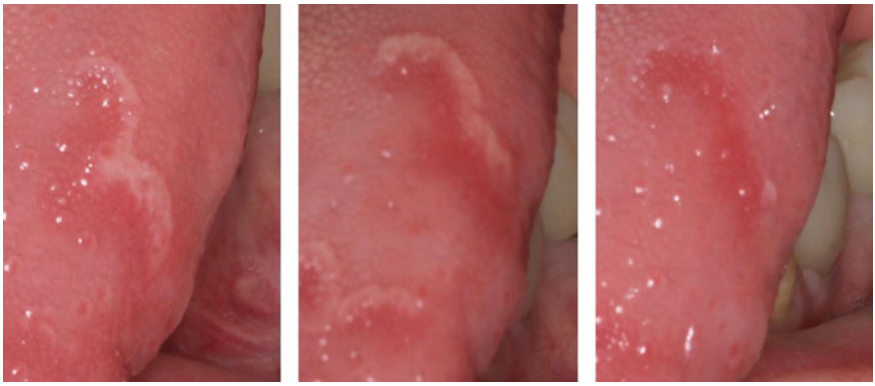

Fig. 3 Evolution of curved GT structures, revealing a RD wave behavior. Time between images: $\Delta t \approx 12$ h (copyright: Wooster Dental)

The only published propagation speed of GT has been given with 1 mm/day by Grosshans and Greber in 1983 [15]. Recent experimental research indicates possible higher propagation speeds (as reported by patients) and the observation of the 'kink eliminating effect' of two waves approaching each other in an angle. The angle between connected RD waves decreases until one straight front evolves. This effect is due to the higher speed of negatively curved front sections as shown in Fig. 3. Mathematically, this effect is given by the Eikonal equation $v = v_0 - DK$, with v, as the velocity of the curved front section, v_0 as the velocity of a straight front, D as a diffusion parameter, and K as the curvature of the front section [16].

3 Patterns on the Skin

The skin of the human body is susceptible to a wide variety of diseases and a resulting pathological redness (*erythema*) can have very different causes (injury, infection, or inflammation). Many abnormal skin conditions can manifest themselves in patterns similar to reaction-diffusion or precipitation waves.

There are numerous pathological and patho-physiological studies of various *erythema* in medical journals but none considers the intersection of reaction-diffusion waves/excitable system and dermatology. The only publication so far, is the report of propagating waves on the skin of a genetically modified mouse by Suzuki et al. in 2003 [17]. Another area of propagating pattern on the skin is in the field of avatars. In general, the skin tone/texture is defined and will not change but there are options to animate the textures of avatars.

The most common structure is an area of redness (*erythema*) in ring form (*annulare*), called a "bull's eye" rash. These patterns can be stationary or non-stationary (*erythema migrans*) spreading from the center (*erythema annulare centrifugum*), first described by Darier in 1916 [18].

Fig. 4 Lupus rash in the form of an early counter-rotating double spiral

Causes of these often expanding, target-like structures (*erythema chronicum migrans*) can be lyme disease (also called *Lyme borreliosis*), an infectious disease transferred primarily by a tick bite. The infection is caused by the spirochete *Borrelia burgdorferi* as identified in the 1980s as the etiological agent. It is the most often reported arthropod transmitted disease in humans in the United States, first reported by Afzelius in 1909 [19] and Lipschütz in 1913 [20]. Afzelius speculated in his 1921 publication that the rash came from the bite of an Ixodes tick [21].

The fungal infection called 'ringworm' (*Tinea corporis*) is a skin disease also appearing as front-like structures. The ringworm is characterized by a red ring of small blisters or scaly skin that grows outward as the infection spreads. This ring sometimes looks like a worm moving around the edges of the border. The center of the ring may clear up, while a new ring of infection develops at the edge of the old ring. Another, non-contagious skin condition is *granuloma annulare*, that usually causes a rash, manifesting in different ways.

Even spiral-like structures can be observed on the human skin. A structure similar to an early stage of a counter-rotating double spiral, as created by disturbing a planar RD wave front, can be seen in Fig. 4. The pattern is a result of *lupus erythematosus*, a name given to a collection of autoimmune diseases in which the human immune system becomes hyperactive and attacks healthy tissues.

A skin condition creating more often spiral-like structures, is *Erythema annulare centrifugum*, which refers to a number of chronic skin conditions which propagate up to 2−4 mm/day (Dutch website www.huidziekten.nl). Examples with spirals, very similar to chemical precipitation pattern as published by Haudin et al. in 2014 [22], are shown in Fig. 5.

Contrary to the Geographic Tongue structures in the previous section, patients with rashes are often treated by their dermatologists. Even if, for example, *Erythema Annulare Centrifugum* disappears on its own over an average of 11 month, patients are often treated with cortical creams. Possible underlying infections are treated with antibiotics and antimycotics as well as antibiotics with anti-inflammatory properties. Lupus and lyme disease are always treated due to their severe effect on the body.

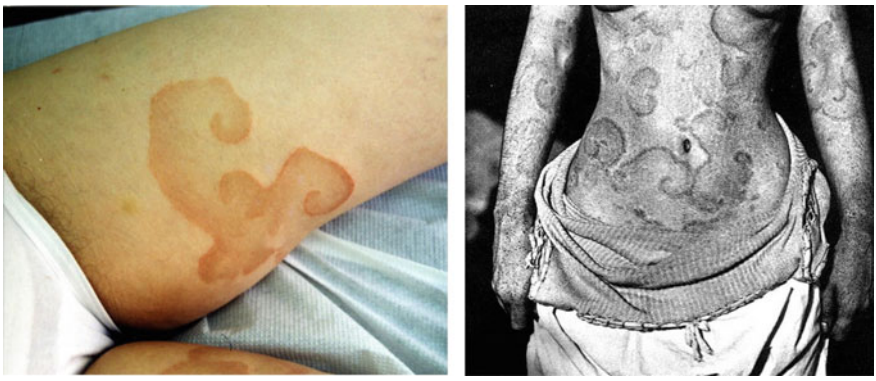

Fig. 5 Multiple spirals of *Erythema Annulare Centrifugum* on the inner thigh and upper body (copyright left: Efstathios Rallis)

4 Spiral with Humans

Besides patterns on humans as described in the previous two parts, there are a few other pattern forming systems *with* humans, which can be described as a reaction-diffusion wave in an excitable medium. In general, pedestrians and car traffic (caused by humans) show organized activities [23]. Other examples are the collective motion at moshpitts at heavy metal concerts [24], crowd disasters [25], but also the more organized wave observed in sports events, the well-known stadium, "La Ola", or Mexican wave [26]. For such a wave, rows of spectators stand up, raise their arms, and sit down again. The neighboring rows, which have not risen yet, will follow the same behavior and thus a wave moves through the spectator rows.

Fig. 6 Human spiral performed by about 550 people. The spiral is created by elevating yellow pages (enhanced for visualization). Image from video at https://youtu.be/172yzGdEa6o

In contrast to a moving front, the largest spiral *with* humans so far has been performed by approximately 550 students, staff, and faculty at Georgia Institute of Technology in Atlanta, GA, USA (video on https://youtu.be/172yzGdEa6o) [27].

The spiral wave is formed with exactly the same rules as in the stadium wave, however for its initiation only a break is required in the symmetry of the propagating wave. Just as in the case of spiral waves in RD systems, a wave needs to be allowed to propagate in only one direction at the start to curl in [27] as shown in Fig. 6.

When a spiral wave is formed by the crowd, it will not stop and continue to rotate until the crowd gets tired. In some cases when some participants do not follow the rules in time, that is they are a bit too slow or a bit too fast, the spiral wave can break into multiple ones and lead to a chaotic dynamics with multiple waves in the system. This is equivalent to what happens in the heart when electrical waves break and there is a transition to fibrillation (see chapter **Spiral Waves in the Heart**).

References

1. M. Williamson, K.C. Brown, The analysis and modelling of British invasions. Phil. Trans. R. Soc. Lond. B **314**, 505–522 (1986)
2. D. Escaff, C. Fernandez-Oto, M.G. Clerc, M. Tlidi, Localized vegetation patterns, fairy circles, and localized patches in arid landscapes. Phys. Rev. E **91**, 022924 (2015)
3. Y. Yamazaki, T. Ikeda, H. Shimada, F. Hiramatsu, N. Kobayashi, J. Wakita, H. Itoh, S. Kurosu, Mi. Nakatsuchi, T. Matsuyama, M. Matsushitatitle, Periodic growth of bacterial colonies. Physica D **205**, 136–153 (2005)
4. A.B. Carey, R.H. Giles Jr., R.G. McLean, The landscape epidemiology of rabies in Virginia. Am. J. Trop. Med. Hyg. **27**, 573–580 (1978)
5. G. Christakos, R.A. Olea, New space-time perspectives on the propagation characteristics of the Black Death epidemic and its relation to bubonic plague. Stoch. Environ. Res. Risk Asses. **19**, 307–314 (2005)
6. A. Scott, *Biology of Plagues - Evidence from Historical Populations* (Cambridge University Press, Cambridge, 2001)
7. E. Pervolaraki, A.V. Holdentitle, Spatiotemporal patterning of uterine excitation patterns in human labour. Biosystems **112**, 63–72 (2013)
8. G. Seiden, S. Curland, The tongue as an excitable medium. New J. Phys. **17**, 033049 (2015)
9. L. Glass, Dynamical disease: challenges for nonlinear dynamics and medicine. Chaos **25**, 097603 (2015)
10. B. Picciani, S. Lavinas, T.A. Domingos, T. Teixeira-Souza, V.C.B. dos Santos, H.F.S. Gonzaga, J. Cardoso-Oliveira, A.C. Gripp, E.P. Dias, S. Carneiro, Geographic tongue and psoriasis: Clinical, histopathological, immunohistochemical and genetic correlation - a Literature review. Anais Brasileiros de Dermatologia **91**, 410–421 (2016)
11. H. Prinz, Wandering rash of the tongue. Dent. Cosmos **69**, 272–275 (1927)
12. J.D. Shulman, Prevalence of oral mucosal lesions in children and youths in the USA. Int. J. Paediatr. Dent. **15**, 89–97 (2005)
13. J. Liang, P. Huang, H. Li, J. Zhang, C. Ni, Y. Wang, J. Yirong, C. Shen, L. Li, J. Kang, H. Chen, Z. Zhang, Z. Wang, M.Li Zhang, Z. Yao, Mutations in IL36RN are associated with geographic tongue. Hum. Genet. **136**, 241–252 (2017)
14. J.D. Shulman, W.M. Carpenter, Prevalence and risk factors associated with geographic tongue among US adults. Oral Dis. **12**, 381–386 (2006)
15. E. Grosshans, F. Gerber, Cinétique des lésions de la langue géographique (Kinematics of lesions in geographic tongue). Ann. Dermatol. Venereol. **110**, 1037–1040 (1983)

16. V.S. Zykov, Analytical evaluation of the dependence of the speed of an excitation wave in a two-dimensional excitable medium on the curvature of its front. Biophys. **25**(5), 906–911 (1980)
17. N. Suzuki, M. Hirata, S. Kondo, Traveling stripes on the skin of a mutant mouse. Proc. Natl. Acad. Sci. USA **100**, 9680–9865 (2003)
18. F.-J. Darier, De l'érythème annulaire centrifuge (érythème papulo-circineé migrateuse et chronique) et de quelques éruptions analogues [Erythema annulare centrifugum (migratory and chronic papulo-circulatory erythema) and some similar eruptions]. Annales de dermatologie et de syphilographie **5**, 57–58 (1916)
19. A. Afzelius, Verhandlungen der Dermatologischen Gesellschaft zu Stockholm, Sitzung vom 28. Oktober 1909 [Proceedings of the Dermatological Society in Stockholm, Meeting 28 October 1909]. Archiv für Dermatologie und Syphilis **101**, 404 (1910)
20. B. Lipschütz, Über eine seltene Erythemform (Erythema chronicum migrans) [Concerning a rare form of erythema (erythema chronicum migrans)]. Archiv für Dermatologie und Syphilis **118**, 349–356 (1913)
21. A. Afzelius, Erythema chronicum migrans. Acta Dermato-Venereologica **2**, 120–125 (1921)
22. F. Haudin, J.H.E. Cartwright, F. Brau, A. De Wit, Spiral precipitation pattern in confined chemical gardens. Proc. Natl. Acad. Sci. USA **111**, 17363–17367 (2014)
23. D. Helbing, Traffic and related self-driven many-particle systems. Rev. Mod. Phys. **73**, 1067–1141 (2001)
24. J.L. Silverberg, M. Bierbaum, J.P. Sethna, I. Cohen, Collective motion of humans in mosh and circle pits at heavy metal concerts. Phys. Rev. Lett. **110**, 228701 (2013)
25. D. Helbing, A. Johansson, H. Al-Abideen, Dynamics of crowd disasters: an empirical study. Phys. Rev. E **75**, 046109 (2007)
26. I. Farkas, D. Helbing, T. Vicsek, Social behaviour: Mexican waves in an excitable medium. Nature **419**(4903), 131–132 (2002). https://doi.org/10.1038/419131a
27. A.J. Welsh, E.F. Greco, F.H. Fenton, Dynamics of a human spiral wave. Phys. Today **70**, 78–79 (2017)