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Statistical analysis of fever interval data

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Abstract. Periodic fever syndromes usually do not show a clear fixed periodicity, and hence cannot be described by the mean and the standard deviation of the interval length. In those cases statistical tools must be used. Fever interval data can be described as a random point process; the renewal density function and its Fourier transform can be used to uncover hidden periodicities. In this report the estimation and evaluation of the renewal density function are described. The data of three patients with periodic fever were investigated. In one of these patients, suffering from periodic fever originating at the level of the hypothalamus, a 30-day periodicity was observed. In a female patient with hyperimmunoglobulinaemia D and periodic fever, menstruation often coincided with or was preceded by a fever episode. In the third patient with a Familial Hibernian Fever-like syndrome, an irregular fever pattern and no periodicity were found. The computerized analysis of the fever intervals may be useful in assessing various periodic fever syndromes.

Keywords. Biorhythm, biostatistics, fever, periodic disease.

Introduction

Patients suffering from recurrent fever are an intriguing problem for the clinician. In some patients, a hidden infection, inflammatory process or malignancy may be responsible for the symptomatology, whereas in others the idiopathic periodic fever syndromes may be the explanation. These latter syndromes include Familial Mediterranean Fever (FMF) [1], Familial Hibernian Fever (FHF) [2] or the hyperimmunoglobulinaemia D and periodic fever syndrome [3]. Rarely, hypothalamic disorders are responsible for the clinical picture of recurrent elevated temperature [4, 5]. Although the adjective 'periodic' suggests some regularity, most often there is no fixed periodicity of the fever attacks. For the present study, we questioned whether there might be some hidden rhythms in some of these syndromes. We therefore performed a computerized analysis of fever interval data in three patients with well-documented periodic fever.

Patients and methods

Patients

Three of our patients with periodic fever syndromes produced ample fever interval data to allow computer analysis.

Patient A is a 72-year-old Dutch male suffering from recurrent episodes of fever (up to 40°C), which last 1 day and are associated with nausea, headache, excessive sweating, and logorrhoea. The attacks have been present since 1971, and recur irregularly about every 2 or 3 weeks. Apart from obesity, physical examination is normal. There is no Cushingoid appearance. Repeated clinical and laboratory investigations have not provided a diagnosis. The patient has a negative noradrenalin provocation test and manifests a high frequency of attacks during medication with colchicine; these results seem to exclude Familial Mediterranean Fever. Serum immunoglobulin D concentrations were low. Unexpectedly, computer tomography of the abdomen disclosed a tumor (size 3 cm) in the right adrenal. This finding initiated endocrine evaluation, which revealed ACTH-dependent rather than primary hyperadrenocorticism. X-rays and computer tomography of the pituitary fossa and hypothalamic region were normal. There was no evidence for hyperthyroidism or presence of a phaeochromocytoma. The clinical findings resemble those of a case reported by Wolff et al. [5] and suggest that our patient could well
be suffering from a hypothalamic abberation, explaining both fever and hormonal abnormalities. The data for the present analysis were provided by the patient who kept a diary of all his attacks.

Patient B is a 25-year-old female of Dutch ancestry suffering from hyperimmunoglobulinaemia D and periodic fever; her case report has been published in detail elsewhere [3]. This patient suffers from febrile attacks since early childhood. The attacks, lasting for approximately 5 days, are preceded by chills and may be accompanied by diarrhoea, swollen lymphnodes and occasionally a painful erythema on the distal part of the extremities. During the attack there is granulocytosis and a rise of acute phase proteins. Serum IgD is always between 3000 and 6000 l⁻¹ (normal range 0–150 l⁻¹). This patient has registered most of her attacks and menstrual data over a period of 8 years, when she was not on oral contraceptives and not using any drug to suppress fever.

Patient C is a 38-year-old male of Dutch ancestry with a lifelong history of recurrent fever episodes, which are accompanied by erythema of the groin and genital region and oedema of the external genital organs. These attacks last 4–5 days. During the attack there is granulocytosis and a rise of acute phase proteins. Extensive investigations did not reveal a primary cause for these episodes, e.g. complementary studies were performed and excluded angioneurotic oedema. The father of this patient may have suffered from a similar condition. The clinical picture of this patient resembles that of Familial Hibernian Fever [2]. The response to glucocorticosteroids has not been fully assessed yet. This patient did not register his attacks himself. The data over a period of 4½ years were reconstructed from the illness records kept by his employer.

Mathematics

In the analysis of fever interval data presented here, an attack of fever is considered to be an event and a series of fever attacks is considered to be a realization of a stochastic (random) univariate point process, in which an event is completely characterized by its time of occurrence. Although the rhythm can be found immediately by using a ruler, the naked eye fails to see it. By increasing the regular rhythm to which random episodes of fever are added (Fig. 1b), the underlying regularity of the pattern cannot be readily discerned. In order to detect such regularities, we have used the (auto-)renewal density function (or conditional intensity function), which is employed for instance in electrophysiology for the analysis of series of action potentials [7, 8].

![Figure 1](image-url)
Because it is impossible to give simple general rules for the interpretation of the renewal density estimate, we have introduced the $E$-function to evaluate the estimate. The $E$-function can assess the significance of a deviation from the random order of intervals. In order to obtain an interpretation of the fever data in the frequency domain, we have calculated the spectrum of counts. The renewal density function, its estimator, the spectrum of counts and the $E$-function are presented in the Appendix.

A generalization of the auto-renewal density function is the cross-renewal density function, which can be used to detect a statistical relationship between two point processes. This function is also described in the Appendix. We have used it to correlate the dates of attacks of fever with the menstrual data of patient B.

**Results**

In the case of patient A, data over a period of 2540 days were available, with 121 attacks of fever. The renewal density function (Fig. 1c) shows a peak at a time-lag of about 30 days, indicating that 30 days after an attack, the probability for a new attack is increased. The $E$-function shows that this peak is very significant (Fig. 1d). The spectrum of counts (Fig. 2a) clearly reveals a 30-day rhythm. The large values of the spectrum at low frequencies indicate that the fever pattern contains slow variations.

In the case of patient B, data on 58 fever attacks in 3380 days were available. The $E$-function of the fever interval data (58 events in 3380 days) in this case did not show significant deviations from a random pattern (not shown). Both fever and menses data were available over a period of 2120 days, with a missing period of 474 days of menses data. The cross-renewal density based on these fever and menses data (Fig. 2b) showed that 0–6 days before menstruation, the probability for an attack of fever was significantly increased. A smaller increase was apparent approximately 28–34 days before menstruation and at 21-27 days after menstruation there is only a small peak in the cross-renewal density.

In the case of patient C, data for only 28 fever attacks over a period of 1760 days were available. Although this number is large enough to allow analysis and to yield results when the regularity is strong, the $E$-function showed no significant deviations from a random pattern.

**Discussion**

The computer analysis, the results of which are summarized in Fig. 2, enabled us to recognize a 30-day rhythm in patient A, a rhythm linked to menstruation in patient B and no pattern in patient C.

The rhythms found in patients A and B could be related to biorhythms, which probably originate at the level of the hypothalamus. In patient A the observed abnormality of the regulation of the hypothalamus-pituitary-adrenal axis is consistent with this suggestion, although it fails to explain fever attacks per se. In patient B, with the hyper IgD syndrome, the analysis suggests that the menstrual cycle significantly increases the chance of an attack. Thus, changes in sex hormones could act as a cofactor in the pathogenesis of a febrile attack. A clustering of attacks around the menstrual period has been observed in a number of patients with Familial Mediterranean Fever (reviewed in [1]).

In patient C, who may be suffering from Familial Hibernian Fever, a relation to a biorhythm is unlikely because the available data give evidence for a random pattern. However, it should be noted that the number of intervals is small. In these kinds of study it is in
general a problem to obtain sufficient trustworthy
data. Very few patients with paroxysmal diseases
appear to keep diaries of their attacks, and medical
charts usually do not contain enough data.

However, from our study it should not be concluded
that the attacks in some patients with periodic fever
syndromes occur on the basis of biorhythms. We
suggest that a number of exogenous factors play a role
as triggers for attacks, but endogenous factors cannot
be denied. The methods given in this paper can be used
to investigate whether attacks of fever relate to other
events. They can be used by bio-statisticians to
investigate periodic fevers and other episodic diseases
and may be helpful in the detection of hypothalamic
disorders.

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Appendix

The (auto-)renewal density function \( R_{xx}(\tau) \) of a point
process \( \{x_i\} \) is defined as the probability to encounter
an event in the time interval \( (t + \tau, t + \tau + \delta) \) given an
event at time \( t \) divided by \( \delta \) and in the limit \( \delta \to 0 \). In
formula:

\[
R_{xx}(\tau) = \lim_{\delta \to 0^+} \frac{\text{Prob(event of } x \text{ in } (t + \tau, t + \tau + \delta) \mid \text{event at } t)}{\delta}
\]  

In order to estimate this function of \( \tau \), a computer
program for point process analysis, VENUS [9], was used
for all calculations presented here. In order to estimate
the renewal density function, the program took into
account the times of occurrence of each event with

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The cross-renewal density function may exhibit peaks
and throws when the two processes are linked, for
instance if an event in \( x \) is often followed by an event in
\( y \), some time \( \tau_{delay} \) later, \( R_{xy}(\tau) \) will exhibit a peak at
\( \tau = -\tau_{delay} \). The cross-renewal density function was
estimated as similar to the auto-renewal density func-
tion. However, it is not by definition a symmetric
function and hence must be estimated for positive as
well as for negative values of \( \tau \).

The Fourier transform of the auto-renewal density
was computed in order to obtain the spectrum of
counts $S_{xy}(f)$ of the interval series [10], which may reveal hidden periodicities. Variance reduction in the spectrum was obtained by applying a Parzen window to the estimated renewal density before transformation [11].

We used shuffling to assess the significance of the renewal density estimates. Suppose that a renewal density $\hat{R}_{xx}(s)$ has been estimated from the set of intervals $\{x_i\}$. Shuffling places these intervals in random order. By computing the renewal densities of $L$ different shuffled series of the same collection of intervals one may compute the average $\bar{R}_{xx}(s)$ and standard deviation $\sigma_{R_{xx}(s)}$ of $L$ renewal densities. (In all actual calculations $L = 100$ was used.) Finally, the $E$-function is computed, which is defined as:

$$E(s) = \frac{\hat{R}_{xx}(s) - \bar{R}_{xx}(s)}{\sigma_{R_{xx}(s)}(s)}$$

The $E$-function is used to give an indication of the randomness of the original series of intervals. For instance, assuming a reasonable amount of data and suitable parameter settings, if $E(s) < -2$ or $E(s) > 2$ occurs for more than 10% of the values of $s$, or if $E(s) > 4$ for some values of $s$, then the original series of fever intervals exhibits a very unlikely ordering. The detailed probability properties of the $E$-function are not yet understood and therefore its trace must be interpreted with care.