Possible repurposing of seasonal influenza vaccine for prevention of Zika virus infection [version 2; peer review: 2 approved]

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Abstract
The in silico analysis shows that the envelope glycoproteins E of Zika viruses (ZIKV) isolated in Asia, Africa and South and Central America encode highly conserved information determining their interacting profile and immunological properties. Previously it was shown that the same information is encoded in the primary structure of the hemagglutinin subunit 1 (HA1) from pdmH1N1 influenza A virus. This similarity suggests possible repurposing of the seasonal influenza vaccine containing pdmH1N1 component for prevention of the ZIKV infection.

Keywords
Zika virus, vaccine, influenza virus, vaccine repurposing, in silico analysis, hemagglutinin, envelope glycoprotein E, informational spectrum method

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Material and methods

Sequences

All sequences of the ZIKV E protein are taken from the NCBI database (http://www.ncbi.nlm.nih.gov/nuccore/?term=zik) and are given in Dataset 1 (accessions: KU312314, KU312315, KU312313, KU312312, KJ776791, KJ634273, KF993678, JN860885, EU545988, HQ234499, KF268948, KF268949, KF623535, LC002520, DQ859059, HQ234501, HQ234500, FSS13025, AHL43505, AHL43503, AHL43502, AMA12087). Sequences for HA1 from influenza viruses were taken from the GISAID database (http://platform.gisaid.org) and are given in Dataset 2 (accessions: EPI705910, EP696955).

Informational spectrum method

The ISM is a virtual spectroscopy technique, developed for the study of protein-protein interactions. The physical and mathematical base of ISM was described in detail elsewhere (5 and references therein), and here we will only in brief present this bioinformatics method.

The ISM technique is based on a model of the primary structure of a protein using a sequence of numbers, by assigning to each amino acid the correspondence value of the electron ion interaction potential (EIIP; L 0.0000, I 0.0000, N 0.0036, G 0.0050, V 0.0057, E 0.0058, P 0.0198, H 0.0242, K 0.0371, A 0.0373, Y 0.0516, W 0.0548, Q 0.0761, M 0.0823, S 0.0829, C 0.0829, T 0.0941, F 0.0946, R 0.0959, D 0.1263). The EIIP values are in Rydbergs (Ry).

The obtained numerical sequence is then subjected to a discrete Fourier transformation which is defined as follows:

\[ X(n) = \sum x(m)e^{-j2\pi nm/N}, \quad n = 1, 2, \ldots, N/2 \]  

where \( x(m) \) is the m-th member of a given numerical series, \( N \) is the total number of points in this series, and \( X(n) \) are discrete Fourier transformation coefficients. These coefficients describe the amplitude, phase and frequency of sinusoids, which comprised the original signal. Relevant information encoded in the primary structure is presented in an energy density spectrum which is defined as follows:

\[ S(n) = |X(n)|^2, \quad n = 1, 2, \ldots, N/2. \]

In this way, sequences are analyzed as discrete signals. It is assumed that their points are equidistant with the distance \( d = 1 \). The maximal
frequency in a spectrum defined as above is \( F = \frac{1}{2d} = 0.5 \). The frequency range is independent of the total number of points in the sequence. The total number of points in a sequence influences only the resolution of the spectrum. The resolution of the \( N \)-point sequence is \( 1/n \). The \( n \)-th point in the spectral function corresponds to a frequency \( f(n) = nf = n/N \). Thus, the initial information defined by the sequence of amino acids can now be presented in the form of the informational spectrum (IS), representing the series of frequencies and their amplitudes.

The IS frequencies correspond to the distribution of structural motifs with defined physicochemical properties determining a biological function of a protein. When comparing proteins, which share the same biological or biochemical function, the ISM technique allows detection of code/frequency pairs which are specific for their common biological properties, or which correlate with their specific interaction. These common informational characteristics of sequences are determined by the cross-spectrum (CS) which is obtained by the following equation:

\[
C(j) = \prod S(i,j)
\]  

where \( \Pi(i,j) \) is the \( j \)-th element of the \( i \)-th power spectrum and \( C(j) \) is the \( j \)-th element of CS. Peak frequencies in CS represent the common information encoded in the primary structure of analyzed sequences. This information corresponds to the mutual interaction between analyzed proteins or their interaction with the common interactor.

**Results and discussion**

The envelope glycoprotein (protein E) which mediates the virus cell entry is highly conserved and virtually identical in all ZIKV isolated during 2015 in countries of Central and South America. Figure 1A shows the IS of ZIKV E isolated in 2015 in Brazil (AMA12087) which is characterized by a dominant peak at frequency \( F(0.295) \). Figure 1B shows the CIS of protein E from ZIKV isolated between 1968 and 2015 in diverse countries of Asia and Africa (Dataset 1). This CIS contains only one dominant peak at frequency \( F(0.295) \). This result suggests that all analyzed ZIKV E encode the same highly conserved information which is represented by the IS frequency \( F(0.295) \). According to the ISM concept\(^6\text{-}^9\), this information determines the interacting profile of ZIKV E.

Previously, it has been shown that frequency \( F(0.295) \) characterizes the human interacting profile of pdmH1N1 HA1 (Figure 2C).\(^7\) It has also been shown that antigens which share a common frequency component in their IS are immunologically cross-reactive (10 and references therein). Presence of the frequency component \( F(0.295) \) in ZIKV E and pdmH1N1 HA indicates that antibodies elicited by this protein of influenza virus could affect interaction between ZIKV E and host proteins. We compared the IS of ZIKV E and HA1 from A/California/07/2009(H1N1) and A/Switzerland/9715293/2013(H3N2) viruses, which are components of the 2015/2016 seasonal influenza vaccine. Results given in Figure 2 and Figure 3A show that ZIKV E and A/California/07/2009(H1N1) encode the common information represented in their IS with the dominant peak at frequency \( F(0.295) \). As can be seen in Figure 3B & 3C, this frequency component is not present in the IS of A/Switzerland/9715293/2013(H3N2) HA1. These results indicate that antibodies elicited by the vaccine virus A/California/07/2009(H1N1) could affect interaction between ZIKV E and host proteins mediating virus cell entry.

**Conclusions**

The presented results of the *in silico* analysis of ZIKV E and host factors mediating viral infection suggest that the seasonal influenza vaccines containing pdmH1N1 as a component, could protect to some extent against the ZIKV infection. Because of the lack of prevention and therapy of the ZIKV disease, in a situation when
Figure 2. (A) The informational spectrum of ZIKV E protein. (B) The informational spectrum of HA1 from A/California/07/2009(H1N1) influenza virus. (C) The consensus informational spectrum of HA1 from pdmH1N1.

Figure 3. (A) The cross-spectrum of ZIKV E protein and HA1 from A/California/07/2009(H1N1) influenza virus. (B) The cross-spectrum of ZIKV E protein and HA1 from A/Switzerland/9715293/2013(H3N2) influenza virus. (C) The cross-spectrum of HA1 from A/California/07/2009(H1N1) and A/Switzerland/9715293/2013(H3N2) influenza viruses.
the ZIKV infection is explosively spreading, this possible safe and inexpensive solution is worth being seriously considered.

Data availability

F1000Research: Dataset 2. Sequences of HA of A/California/07/2009(H1N1) and HA of A/Switzerland/9715293/2013(H3N2) taken from the GSAID database (accessions: EPI705910, EPI696955), 10.5256/f1000research.8102.d11432612

Author contributions
Conceived and designed the study: VV SP. Analyzed the data: VV. Wrote the paper: VV SP.

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References

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Patrizio Arrigo
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I've checked the second revised version and it agrees with my suggestions. I guess it can now be indexed

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 1

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This manuscript provides important information on the envelope of Zika virus that will help to produce a vaccine.

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.
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The paper summarizes an application of well established and efficient ISM method to compare ZIKA and H1N1. I would like to underline two points that I guess to be better describe. I suggest that Figure 2 can contain also the consensus spectrum as Figure 1.

The second point is the description of Figure 3 in the result section. I guess that the authors could extended the illustration of the differences of the cross-spectrum. These differences are very interesting data for discrimination. Another small remark is about the aim of the paper. The authors suggest a ‘repositioning’ of H1N1 vaccine if it is possible I would like to ask them if they have considered the possibility to elicit unfavourable effect of cross reactivity with the consequence to reduce the vaccine efficiency.

Competing Interests: No competing interests were disclosed.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

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