

Importance of Fluctuating Amino Acid Residues in Folding and Binding of Proteins

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Abstract

Background: Conformational flexibility of proteins remains as one of the major events in protein-protein/DNA/ligand/small molecule binding to achieve its biological function in the cell. The availability of high-resolution structures of protein complexes is a valuable resource for researchers to understand the mechanisms behind such interactions and it is found that the flexibility of amino acid residues at binding sites is crucial for many important functions in the cell.

Methods: In this article, our statistical method (PreFRP) developed based on fluctuating amino acid residues and various amino acid indices related to flexibility/rigidity were used to study the importance of fluctuating amino acid residues in theonucleases from pathogenic bacteria, cell penetrating peptides and intrinsically disordered proteins responsible for many neural disorders.

Results: The results from our analysis reveal the importance of fluctuating amino acid residues in folding and binding of proteins. The role of moderate and high fluctuating residues in theonucleases, cell penetrating peptide and disordered regions are discussed in detail.

Conclusion: Therefore, our analysis will help in understanding the importance of fluctuating amino acid residues in proteins which undergo a conformation change phenomenon.

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Introduction

Proteins are functional units of the cell and play many important roles in various cellular processes like transport, metabolism, and signaling. The collection of proteins within a cell determines its health and function and the proteins in the cell interact with other proteins/DNA/small molecules to perform biological functions. During these interactions, the amino acid residues at the interface/binding site alter conformation in such a way to attain stability ¹. Recognizing or identifying the binding sites in a protein is one of the major goals of bioinformatics. It was believed that the extraction of biologically relevant features of the binding sites of proteins may ultimately lead to accurate prediction of binding sites ². The problem with this kind of approach is due to lack of our understanding of what investigated homologous subsequences in the 3D structure of proteins and reported surprising structural adaptability of identical subsequences ³. Wilson *et al* stated that common sequences of up to eight residues do occur in unrelated proteins and sequence-specific antibodies

can be generated to test binding to identical sequences contained in unrelated proteins ⁴. Argos has examined the most frequently observed residue substitutions and their correlation with structural changes in the oligopeptide pairs of identical pentapeptides in unrelated proteins which yielded a possible guide for site-directed mutagenesis experiments when no tertiary structural information is at hand ⁵.

Minor and Kim have designed an 11 amino acid sequence (chameleon sequence fragment) that folds as an alpha helix in one position and beta sheet at another position of the IgG binding domain of the protein and they demonstrated that non-local interactions can determine the secondary structure of peptide sequences of substantial length ⁶. After a careful study, Dalal and Regan demonstrated careful selection of key amino acid residues to manipulate the balance of short and long-range interactions which stabilize either a helical or sheet conformation ⁷. Using all the knowledge provided by the various protein science research groups, it is clear that

Fluctuating Amino Acid Residues in Proteins

Table 1. Fluctuating amino acid residues: High, moderate and weak fluctuating amino acid residues

Fluctuating type	Amino acid residues
High fluctuating amino acid residues	Glycine, Alanine, Serine, Proline and Aspartic acid
Moderate fluctuating amino acid residues	Threonine, Glutamic acid, Asparagine, Lysine, Cysteine, Glutamine, Arginine and Valine
Weak fluctuating amino acid residues	Histidine, Leucine, Methionine, Isoleucine, Tyrosine, Phenylalanine and Tryptophan

the fluctuating amino acid residues at binding sites or at certain positions are important for folding and binding of proteins.

Materials and Methods

Definition of fluctuating residues and amino acid indices

The definition of high, moderate and weak fluctuating amino acid residues by Ruvinsky *et al*⁸ is presented in table 1 and is used in this study. The five highly fluctuating amino acid residues are glycine, alanine, serine, proline and aspartic acid, respectively. Glycine and alanine are two small hydrophobic amino acids as the most flexible molecules in proteins. Serine contains an OH group in side chain which can form a hydrogen bond, whereas aspartic acid contains a carboxylic acid in side chain which can lose a proton to give a negatively charged COO⁻. The role of five fluctuating residues in protein structure, folding and stability has been revealed in our previous studies^{9,10}.

Hydrophobicity as a physicochemical property is effectively used to characterize secondary structures of proteins and it is considered as a dominant force for protein folding⁹ and hence, 70 amino acid indices from AA index database (<https://www.genome.jp/aaindex/>) were the focus of this study. The indices related to hydrophobicity which reflect flexibility and rigidity were carefully selected from database. The twenty amino acid residues are written in order (higher to lower values of their property) to understand the contribution of fluctuating amino acid residues in proteins. The position-specific matrix of each amino acid residue in the indices is given in table 2.

Prediction and visualization of fluctuating residues

In our previous work, a web server "PreFRP" was developed to visualize and predict fluctuating amino acid residues in proteins¹¹. The web server gets a Protein Data Bank file or sequence file to perform prediction of

Table 2. Position profiles of amino acid residues in various hydrophobicity indices

Position	A	C	D	E	F	G	H	I	K	L	M	N	P	Q	R	S	T	V	W	Y
1	0	16	1	1	7	3	0	11	2	2	1	0	0	1	10	0	0	2	10	3
2	1	4	5	3	10	0	1	12	5	5	2	1	0	0	1	0	0	9	7	4
3	0	1	3	3	12	1	1	11	3	5	4	2	0	2	2	0	0	9	7	4
4	0	4	0	5	8	1	0	7	1	12	4	5	5	2	2	2	2	6	3	1
5	3	3	1	1	6	0	3	3	2	15	2	3	1	4	0	3	0	7	6	7
6	2	2	5	1	6	1	1	3	2	9	13	2	2	2	2	0	0	10	2	5
7	8	3	1	1	3	1	5	2	3	0	13	2	4	4	0	3	3	5	5	4
8	7	7	0	2	1	8	3	0	0	2	9	1	2	1	2	2	7	1	3	12
9	6	4	0	2	0	3	10	1	6	1	3	1	6	2	2	4	7	3	4	5
10	16	6	1	2	1	9	5	1	0	1	1	0	3	2	0	7	8	0	1	6
11	9	3	2	2	0	14	9	2	0	3	0	3	5	1	1	6	7	0	2	1
12	4	3	0	5	0	3	6	0	5	1	1	3	3	1	4	3	17	2	4	5
13	3	1	3	3	0	3	8	2	5	0	5	2	7	2	9	7	2	1	3	4
14	3	1	8	5	0	3	6	0	3	0	4	2	7	8	5	5	2	1	4	3
15	1	4	5	4	1	3	2	1	2	0	1	11	7	6	3	7	7	5	0	0
16	1	0	6	6	2	5	2	3	1	2	2	13	5	4	1	5	3	4	3	2
17	1	4	5	11	1	3	2	1	2	5	0	8	6	8	1	6	0	3	2	1
18	3	2	9	8	0	4	2	5	3	4	0	5	0	10	7	4	1	1	0	2
19	1	1	12	2	5	1	1	4	9	2	4	5	3	4	7	5	3	0	0	1
20	1	1	3	3	7	4	3	1	16	1	1	1	4	6	11	1	1	1	4	0

Fluctuating Amino Acid Residues in Proteins



Figure 2. Amino acid composition in cell penetrating peptides.

Fluctuating residues in thermonucleases

The fluctuating index for the amino acid residues in thermonucleases along the sequence is shown in figure 1. The high and moderate fluctuating amino acid residues occur in higher percentages (28.9 and 49.1%). From our results, it is clear that the moderate fluctuating amino acid residues dominated in comparison to the other two types of fluctuating residues. Therefore, the distribution of high and moderate fluctuating residues helps the formation of secondary structure, mainly helices.

Fluctuating residues in cell penetrating peptides

The amino acid composition of cell penetrating peptides is shown in figure 2. Comparison between amino acid compositions of cell penetrating peptides reveals the higher occurrences of high fluctuating amino acid residues. In figure 3, the lack of formation of secondary structure is evident due to the presence of high fluctuating amino acid residues in cell penetrating peptides. The random coil state of the peptides will form a regular secondary structure like helix or strands while binding with protein/DNA. Interestingly, the cell penetrating peptides are rich in cysteine, which can form disulfide bridges and contribute to the stability of peptides.

Fluctuating amino acid residues in intrinsic disordered proteins

Analysis of sequence composition of ordered and disordered proteins has shown the difference and defines tertiary structures with fundamental knowledge for understanding molecular assembly and protein folding¹⁴. The high fluctuating residues dominated in the case of sequences of intrinsically disordered proteins, whereas moderate fluctuating residues dominated in other cases. The prediction scores of four different methods such as G plot, Ronn, Ponder and PreFRP, respectively were computed and compared. Both positive and negative numbers in PreFRP helped to classify the ranking system better than entirely negative or positive ones (Figure 4). The methods used for comparison and its scoring scheme are shown in table 3 and the results imply that PreFRP performs comparatively better prediction like other methods.

Discussion

Despite the explosive growth in the number of high-resolution 3D protein structures, a key challenge for protein scientists is to understand how the sequence of

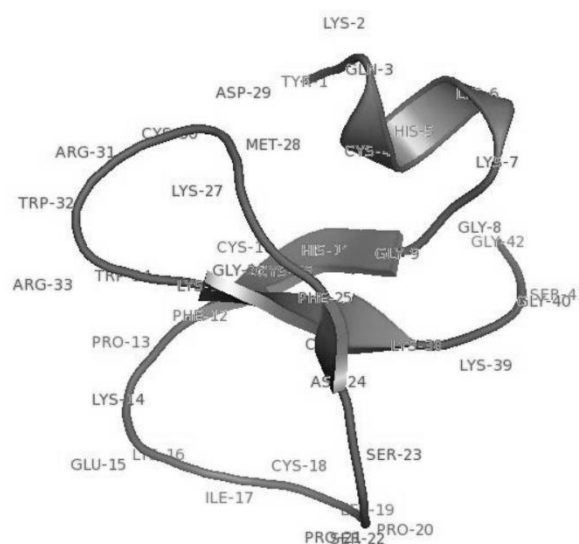


Figure 3. Random coil behavior of cell-penetrating peptides with more high fluctuating residues.

amino acid residue code for a particular fold. Statistical analysis of sequence compositions of native folded protein structures revealed the role of certain amino acid residues in regular (helix or extended) and irregular regions (coil-like states). The conformation change phenomenon is mainly driven by high fluctuating residues occur at irregular regions and these residues play important role in folding and binding. Many computational methods were developed to identify fluctuating residues

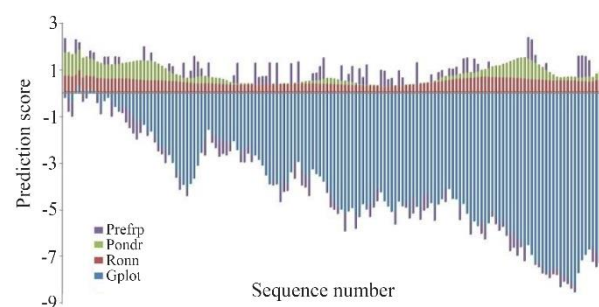


Figure 4. Comparison of prediction scores of four different predictors.

which mainly rely on the sequence or structural similarity. However, the existing methods cannot achieve high accuracy due to less conservation of fluctuation residues in homologous sequences and hence, a statistical

method (PreFRP) to predict the amino acid residues in proteins as high, moderate and weak fluctuating was developed in this study. The PreFRP method focuses on the effective relationship between protein sequence, ability to undergo conformation change and functionality of protein structures.

Conclusion

In the present study, the higher composition of high and moderate fluctuating amino acid residues in thermocleaves, cell penetrating peptides and intrinsically disordered protein regions was identified. Moreover, the location of high fluctuating amino acid residues in various classical amino acid indices were analyzed and discussed which are classified based on flexibility and rigidity property. Through the article, the importance of fluctuating amino acid residues in conformation change phenomenon was explored which helps protein scientists to understand the role of fluctuating residues in folding and binding of proteins.

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Conflict of Interest

The authors declare no competing financial interests.

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