

Protein structure modeling for variant pathogenicity prediction

Author: Sylt Schuurmans

Studentnumber: 333332

Study: Bio-informatica

Hanze hogeschool: Institute for Life Science and Technology

Hospital: University Medical Center Groningen: Department of Genetics

Supervisor : Joeri van der Velde

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Abbreviations

APAF1 Apoptotic Protease Activating Factor

DNA Deoxyribose Nucleic Acid

MD Molecular Dynamics

TNF Tumor Necrosis Factor

TNFRSF1A Tumor Necrosis Factor Receptor Superfamily Member 1A

TRAPS Tumor Necrosis Factor Associated Receptor-Associated Periodic Syndrome

VIPUR Variant Interpretation Using Rosetta

VTS VIPUR Training Set

Introduction

Around 1 in 17 people is affected by one of 7,000 known rare diseases. Most of these patients do not receive a diagnosis, which means they remain in uncertainty without a prognosis, are unable join specific patient support groups, and do not receive the most appropriate treatment. Next-generation sequencing (NGS) of DNA promises to establish a molecular diagnosis and help these patients but many challenges still stand in the way of maximum success. Recent years have seen great advances in computational tools that quickly reduce the amount of DNA variants to be interpreted by a human expert for potentially pathogenic effects. Although algorithms can now safely remove around 95% of the harmless variants, this still leaves hundreds of variants to be investigated for a whole-exome sequenced patient, which is far too much for a quick and clear diagnosis. Current tools to predict variant pathogenicity rely on indirect evidence such as evolutionary conservation, annotation of regulatory genomics elements or structural DNA features. A refreshing alternative was presented by VIPUR which shows the potential of structural modelling of proteins to predict the actual effect of a specific variant on the function of that protein. However, this predictor was not integrated with the latest and greatest variant pathogenicity prediction approaches, was done on relatively small number of variants, and did not result in a tool that is ready to be taken into routine diagnostic practice.

1 Cell Death

1.1 Cell Death

Each human has about 37.2 trillion cells (3.72×10^{13}) of which several types are relative short lived compared to the life expectancy of a human in 2016. Continuously cells die by programmed cell death which is called apoptosis, this process allows to make certain features arise and keep cell growth in check. The process of apoptosis can be triggered by pathways that activate caspases (proteases that cleave aspartate in proteins), once the process starts it is irreversible and the amount of caspases within the cell increases and is going to disrupt the cell's metabolism. The internal system that determines when apoptosis initiates is the intrinsic pathway, it activates when there is internal stress in the cell such as damaged DNA or proteins (Which can be caused by: heat, hypoxia, radiation, low/high ion concentration within a cell). If stress is detected a mitochondrion releases cytochrome c into the cytosol and triggers a cascade, cytochrome c binds to apoptotic protease activating factor 1 (APAF1) and starts to activate (initiator) caspase 9 that activates caspase 3 and thereby destroys protein structures within the cell.

are possible for activating the process and are caused by separate pathways. Both pathways lead to the activation of death-inducing signaling complex (DISC). This process is dependent on several

1.2 Tumor Necrosis Factor Receptor Associated Syndrome

1.3 Tumor Necrosis Factor Receptor Super Family Member 1A

1.4 Tumor Necrosis Factor Alpha and Beta

2 Protein Modeling Techniques

3 Monte Carlo

4 Materials and Methods

4.1 Two methods: scale and detail

VIPUR is a relative large scale approach for analyzing protein structure variants and requires several tools from the Rosetta software suite (Section 4.2.4) to acquire the majority of its features, the remainders are collected from PSI-BLAST (Section 4.4) and the solvent accessible surface area (SASA) with Probe (Section 4.5). Features from the proteins acquired by analyzing the structures with Probe and Rosetta were collected from Modbase [] and SWISS-MODEL []. Not all structures that were used from the databases for machine learning were complete, there were structures of which only pieces were experimentally determined and for some no structure was available. To level this problem homology models were made with Modeller (Section 4.6 based on known homologous structures. In some experimental determined structures duplicate chains, ligands, metals and non-standard amino acids were present, these inconsistencies were able to alter the features generated by software and could in some case hinder feature collection, were therefore removed.

Another approach is by individually assessing a single gene product and determining the effects of a mutation by inserting, replacing or removing a residue and remodeling the structure. This process has been investigated for TNFRSF1A (Section 1.3)

With the VIPUR approach treating each protein similar by its current methods an alternative method the same by applying each method on all structures and a different method an uncertain how it will behave a more traditional approach was also take. A different approach that was taken by investigating a single protein (Section ??) structure and its thorough investigation of changes within the

Models within the VIPUR training set (VTS) had different Models acquired from t Proteins within the VIPUR training set (VTS) were a full structure had only parts or none Not every protein used within the VIPUR Training Set (VTS) had a whole structure or

Within the approach proteins that had no experimental structure available were homology modeled with Modeller (Section 4.6), parts and whole structures from proteins were collected from Another approach Another approach that was taken was to thoroughly investigate

Protein variants were analyzed in large groups by the VIPUR approach by several tools to which machine learning was applied.

4.2 Rosetta

For the prediction and analysis of protein structures the Rosetta software suite was used, it contains various tools for protein, antibody analysis and design []. The scores generated for the machine learning within the VIPUR approach rely on results generated by Rosetta software and to apply this approach the steps are reproduced. Several strategies were employed for realizing mutated structures, the first strategy was to identify the whole structure of proteins

4.2.1 Relax

4.2.2 Abinitio

4.2.3 Backrub

4.2.4 Rescore

4.3 BLAST

4.4 PSI-BLAST

4.5 Probe

4.6 Modeller

4.7 RCSB

4.8 Uniprot

The initial structure of the protein was produced with the application abinitio relax. For the prediction the application requires an amino acid sequence to identify homologous sequences in a curated database. Homologous sequences within the database are found by the BLAST algorithm, when a

For the search of the sequences it uses the BLAST algorithm and to find homologous amino acid sequences which have protein structures.

requires an amino acid sequence and it takes an amino acid sequence as input and searches in a curated protein database BLAST for finding homologous sequences.

to align sequences with to acquire homologous sequences. The homologous With these sequences it finds structures related to the protein For the prediction of the initial structure of TNFR the application abinitio relax was used.

With this tool a sequence is inserted as input that is aligned to

4.9 I-TASSER

4.10 PyMOL

Visualization of 3D structures, making images of proteins and putting the known orientations of monomers in position were done in PyMOL [1]. Since some protein structures consist of multiple identical monomers they are left out of the structure and supplied with information about how the monomers are position to form the whole oligomer structure (Sections 4.7, 4.8).

5 Results

6 Discussion

People with rare diseases are hard to diagnose

Prediction of pathogenicity in variants momentarily done based on sequence information and has been successful for certain groups of genes [1]. However pathogenicity of some genes with their variants cannot be classified by the currently used features for classification. Recently a method, called VIPUR, surfaced that incorporated sequence and protein data for classification of the pathogenicity from gene variants[2].

In the attempt to reproduce the methods taken by the VIPUR approach on protein structures that are related to rare diseases it was realized that some questionable steps were being taken. With this approach all ligands were removed [3] which changes the energies within and can therefore alter the structure [4] and causes it to be analyzed from a single perspective instead of two when a bound ligand is also taken into account. Another step that was taken with VIPUR is that each structure is viewed as a monomer which is for some proteins not a problem, but for a complex that consists of multiple similar or a variety of different monomers makes it difficult to assess the effects.

To make predictions for new benign and pathogenic variants from TNFRSF1A, more information should be collected on how certain residues contribute to TNFRSF1A. More differences between interaction energies in mutated proteins could have been found by adding molecular dynamics (MD) simulations of TNF α/β separately TNFRSF1A and combined with TNF docked into TNFRSF1A.

prediction of potential benign and pathogenic variants of TNFRSF1A isoforms should be included in the analysis to gain insight in which part of the proteins are highly important for the interactions and could result in a better prediction.

A significant contribution to gain more insight in how TNFRSF1A interacts with TNF α/β would have been the addition of molecular dynamic simulations; it shows how the proteins move on their own but also how the residues of the protein and the ligand interact with each other.

The VIPUR pipeline could not be executed because it was not possible to compile PyRosetta or PyMOL on the cluster.

Isoforms were not taken into account.

some steps have become questionable in structure of TNFRSF1A some questionable rare diseases some questionable training set some q to reproduce some of the results that were acquired with the VIPUR some questionable assu

Looking at the investigation t

With the resource at our disposal we were unable to reproduce any of the results that were produced by VIPUR for testing purposes, by

7 Conclusion

Supplementary