TACT: Transcriptome Auto-annotation Conducting Tool of H-InvDB

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ABSTRACT

Transcriptome Auto-annotation Conducting Tool (TACT) is a newly developed web-based automated tool for conducting functional annotation of transcripts by the integration of sequence similarity searches and functional motif predictions. We developed the TACT system by integrating two kinds of similarity searches, FASTY and BLASTX, against protein sequence databases, UniProtKB (Swiss-Prot/TrEMBL) and RefSeq, and a unified motif prediction program, InterProScan, into the ORF-prediction pipeline originally designed for the ‘H-Invitational’ human transcriptome annotation project. This system successively applies these constituent programs to an mRNA sequence in order to predict the most plausible ORF and the function of the protein encoded. In this study, we applied the TACT system to 19 574 non-redundant human transcripts registered in H-InvDB and evaluated its predictive power by the degree of agreement with human-curated functional annotation in H-InvDB. As a result, the TACT system could assign functional description to 12 559 transcripts (64.2%), the remainder being hypothetical proteins. Furthermore, the overall agreement of functional annotation with H-InvDB, including those transcripts annotated as hypothetical proteins, was 83.9% (16 432/19 574). These results show that the TACT system is useful for functional annotation and that the prediction of ORFs and protein functions is highly accurate and close to the results of human curation. TACT is freely available at http://www.jbirc.aist.go.jp/tact/.

INTRODUCTION

Automatic prediction of functions of transcripts is extremely important and useful; it has a wide variety of applications in studies based on sequence data of the genome, cDNAs and ESTs in various species, especially in human. Studies on human transcripts have been systematically and extensively carried out to draw the outline of the human transcriptome (1–5). Some other studies have reported the functional annotation of \textit{Mus musculus} (6) and \textit{Arabidopsis} (7) full-length cDNAs. However, the functional annotation of those transcripts relied heavily on human curation because currently there is no freely available web server to provide the automated functional annotation.

The human transcriptome consists of protein-coding and non-protein-coding functional RNAs. Several sequence analysis techniques are available to provide insights for predicting the function of the transcripts to some extent. For example, sequence similarity search tools, such as BLASTX (8) and FASTY (9) provide the homologs of the transcripts in protein databases and motif prediction programs, such as InterProScan (10) will provide the predicted functional motifs in the protein-coding sequence (CDS) of the transcripts. However, any one of these alone is not enough to comprehensively judge and assign the function of the transcripts as

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protein-coding genes. Thus, an integration of sequence analysis tools is necessary.

We have previously reported the integrative annotation of human genes by the international cooperative project entitled ‘Human Full-length cDNA Annotation Invitational’ (abbreviated as H-Invitational or H-Inv) and the construction of an integrative database of the human transcriptome, named H-Invitational Database (H-InvDB) (11,12). In the H-Invitational project, we collected information about human full-length cDNAs, and conducted extensive bioinformatics analyses by making full use of biological databases and computational tools and rearranging annotation by biologists (13). A standard for human curation was proposed, established and applied to annotate all the collected H-Inv cDNAs. We assigned the standardized functional annotation to 19 574 representative H-Inv proteins by human curation, based on the results of similarity search and InterProScan (11,12). In this study, we describe the newly developed transcriptome auto-annotation conducting tool (TACT), a web-based automated prediction tool for functional annotation that was originally designed for the H-Invitational project. We developed the TACT system by integrating two kinds of similarity searches, BLASTX (8) and FASTY (9), against protein sequence databases and a unified motif prediction program, InterProScan (10), into the ORF-prediction pipeline. This system successively applies these constituent programs to an mRNA or cDNA sequence in order to predict the most plausible ORF and the function as a protein. Furthermore, we applied the TACT system to 19 574 non-redundant human transcripts registered in H-InvDB, and evaluated its predictive power by the degree of agreement with the functional annotation results resulting from human curation.

TACT COMPUTATIONAL PIPELINE

The TACT computational pipeline was developed by integration of two sequence similarity searches, BLASTX and FASTY, and a motif prediction by InterProScan. The computational analyses can be divided into three pipelines; sequence analysis, ORF prediction and auto-functional annotation pipelines, and is carried out as follows (Figure 1).

TACT sequence analysis pipeline

All the repetitive and low-complexity sequences in a query sequence are masked using RepeatMasker (http://www.repeatmasker.org) with Repbase. The masked sequence is then subjected to BLASTX and FASTY against UniProtKB (Swiss-Prot/TrEMBL) and RefSeq (human) protein entries. In parallel, GeneMark (14) ORF prediction is carried out.

TACT ORF prediction pipeline

Then, TACT proceeds to predict the ORF of each sequence by using a custom-made Perl script based on the similarity with UniProtKB (Swiss-Prot/TrEMBL) and RefSeq (human) protein entries and prediction by GeneMark (14). The translated region (ORF) of each sequence is predicted by one of five methods in order of priority [illustrated in Supplementary Figure 1A in our previous study (11)]: (i) prediction based on complete sequence match with known (experimentally verified) reviewed human RefSeq or UniProtKB/Swiss-Prot protein entries; (ii) prediction based on similarity with known RefSeq, UniProtKB/Swiss-Prot or UniProtKB/TrEMBL entries; (iii) prediction based on similarity with hypothetical RefSeq, UniProtKB/Swiss-Prot or UniProtKB/TrEMBL entries; (iv) prediction by GeneMark with probability larger than 0.5 and length longer than 80 amino acids; (v) the longest possible translation of initiation to termination codon in six frames of length greater than 80 amino acids.

TACT auto-functional annotation

For each sequence with predicted ORF, TACT conducts InterProScan (10). Then the automated-functional annotation for each sequence is predicted by using a custom-made Perl script applying five standards in order of priority. TACT assigns the most appropriate protein or domain ID, named as ‘data source ID’, to describe the functions of transcripts as proteins and classifies them according to five similarity criteria [illustrated in Supplementary Figure 2B in our previous study (11)]: (i) identical hit by BLASTX or FASTY (identity ≥ 98% and
A problem in assigning data source IDs to transcripts is that the data sources are sometimes proteins without experimental verifications. We thus introduced a text-based judgement scheme to determine ‘known proteins’ and ‘meaningful InterPro domain’. In practice, we avoided proteins with the following keywords that suggest proteins without experimental verification in the description: (i) hypothetical, (ii) similar to, (iii) names of cDNA clones (Rik, KIAA, FLJ, DKFZ, HSPC, MGC, CHGC and IMAGE) and (iv) IDs of InterPro domain frequent hitters. Hits to proteins with these keywords are automatically ignored.

For any sequence with no predicted ORF, the definition of the sequence is automatically annotated as ‘Non-protein-coding transcript’.

Several additional sequence analyses were integrated into the TACT annotation system to provide useful reference data. For example, Gene ontology (GO) terms are assigned through the relations of InterPro IDs to GO terms. All the results of the analysis and annotated data are temporarily stored in a PostgreSQL database and are made accessible through the TACT web-based interfaces (Figure 1).

**ACCURACY OF TACT**

In the H-Invitational annotation project, we assigned each transcript the most appropriate protein or domain ID, named as ‘data source ID’, to describe the function of cDNA as a protein. The judgement was done one by one by human curation, following a standard scheme [illustrated in Supplementary Figure 4 in our previous study (11)].

Figure 2. TACT web-based interfaces. Sample views of TACT top (A), data submission (B) and annotation view (C) for HIT000017619 (AK092752) are shown. The annotation view (C) shows detailed annotation information and has links to external databases as indicated. The blue arrows indicate the flows of views during the TACT analysis and black lines indicate the links to appropriate reference data in H-InvDB or external public databases.
19,574 representative H-Inv cDNAs, we conducted functional annotation by human curation using a custom-made annotation system. In this report, we evaluated the accuracies of the TACT system by the agreements between TACT annotation and human curation for 19,574 representative H-Inv cDNAs. The overall agreement was 83.9%, i.e. 16,432 TACT annotations, including those annotated as hypothetical proteins, agreed with H-Inv human curation. This result shows that by integrating three sequence analysis programs, the prediction of functional annotation becomes highly accurate and closer to the results of human curation.

In our annotation pipeline, we classified proteins into five similarity categories (Table 1): Category I proteins were defined as ‘Identical to a known human protein’; Category II proteins were defined as ‘Similar to a known protein’; Category III proteins were defined as ‘Domain-containing proteins’; Category IV proteins were defined as ‘Conserved hypothetical proteins’; Category V proteins were defined as ‘Hypothetical proteins’. The agreements of TACT annotation with H-InvDB for each similarity category are summarized in Table 1. In the H-Inv annotation project we checked the abstracts in PubMed (http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?db=PubMed) corresponding to the candidate protein entries for data source ID in the human curation procedure. The agreement was the lowest in Category II. For example, for HIT000012743 (AK056129), TACT auto-annotation output Q91YE4 as data source ID, so that the definition of the cDNA was ‘Similar to 67 kDa polymerase-associated factor PAF67’ [Category II; Similar to a mouse (Q91YE4) protein]. However, by checking the PubMed abstracts for Q91YE4, we found that the annotation should be altered to ‘TPR repeat containing protein’ [Category III; InterPro domain (IPR001440)-containing protein] because the function of Q91YE4 was not yet examined experimentally. This example illustrates the importance of human curation in functional annotation of transcripts. Also, exclusion of proteins described in specific PubMed entries is a possible way of improving the accuracy of TACT auto-functional annotation pipeline. The human-curated annotation was provided at the appropriate cDNA view in H-InvDB (http://www.jbirc.aist.go.jp/hinv/soup/pub_Detail.pl?hinv_id=HIT000012743).

**TACT WEB-BASED INTERFACES**

TACT web-based interfaces consist of the TACT top page, the TACT data submission and the TACT annotation view. In the TACT top page, general information about TACT and data input facilities are provided (Figure 2A). In the TACT data submission, the selections of the analysis options are provided (Figure 2B). It is recommended that users select all the options to achieve the highest accuracy. After selecting the options, users can check the input sequence data and the progress of the analysis just after submitting the annotation. By entering an e-mail address, the URL for the annotation results will be reported to users by e-mail when all the analysis has been completed. The TACT annotation view shows all the annotation of the input sequence. It consists of six sections: auto-functional annotation information section; mapping information section; cDNA information section; predicted ORF section; predicted motif information section and predicted subcellular localization section. The data include the functional description as protein-coding transcripts, similarity category, predicted ORF, translation, predicted functional motifs by InterProScan, GO and input nucleotide sequence in DNA database (Figure 2C). If the DNA accession number of the input data are already recorded in H-InvDB, then the location in the human genome, and corresponding H-Invitational transcripts (HIT) and H-Invitational cluster (HIX) IDs with hyperlinks to H-InvDB will also be provided. As shown in the sample Annotation view in Figure 2, this view also links to many external public databases including DDBJ/EMBL/GenBank, RefSeq, UniProtKB/Swiss-Prot, InterPro and GO.

**Table 1. The degree of agreement of TACT annotation and human curation**

<table>
<thead>
<tr>
<th>Similarity category</th>
<th>Description</th>
<th>No. of H-Inv proteins examined</th>
<th>No. of correctly predicted proteins by TACT</th>
<th>The agreement of TACT annotation and human curation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Identical to a known human protein. (Identity ≥98% and coverage =100%)</td>
<td>5313</td>
<td>4735</td>
<td>89.1</td>
</tr>
<tr>
<td>II</td>
<td>Similar to a known protein of any species. (Identity ≥50%)</td>
<td>5859</td>
<td>3469</td>
<td>59.2</td>
</tr>
<tr>
<td>III</td>
<td>InterPro domain-containing protein</td>
<td>1387</td>
<td>1320</td>
<td>95.2</td>
</tr>
<tr>
<td>IV</td>
<td>Conserved hypothetical protein</td>
<td>1309</td>
<td>1265</td>
<td>98.9</td>
</tr>
<tr>
<td>V</td>
<td>Hypothetical protein</td>
<td>5706</td>
<td>5643</td>
<td>96.6</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>19,574</td>
<td>16,432</td>
<td>83.9</td>
</tr>
</tbody>
</table>
CONCLUSION
In this study, we showed that by integrating three sequence analysis programs, the prediction of ORFs and protein functions becomes highly accurate and closer to the results of human curation. Because of its accuracy and usefulness, TACT will be an indispensable tool to predict the function of transcripts. The TACT system can always provide the latest reference information because protein and motif databases are updated regularly and frequently. This unique system for conducting functional annotation may have a wide range of application in transcriptome studies of human and other species. TACT is freely available at http://www.jbirc.aist.go.jp/tact/.

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REFERENCES