11.2: Protein translation

Translation is the process by which mRNAs are converted into protein products through the interactions of mRNA, tRNA, and rRNA. Even before an mRNA is translated, a cell must invest energy to build each of its ribosomes, a complex macromolecule composed of structural and catalytic rRNAs, and many distinct polypeptides. In eukaryotes, the nucleolus is completely specialized for the synthesis and assembly of rRNAs.

Ribosomes exist in the cytoplasm and rough endoplasmic reticulum of eukaryotes. Ribosomes dissociate into large and small subunits when they are not synthesizing proteins and reassociate during the initiation of translation.

- In *E. coli*, the small subunit is described as 30S, and the large subunit is 50S, for a total of 70S (recall that Svedberg units are not additive).
- Mammalian ribosomes have a small 40S subunit and a large 60S subunit, for a total of 80S. The small subunit is responsible for binding the mRNA template, whereas the large subunit sequentially binds tRNAs.

Each mRNA molecule is simultaneously translated by many ribosomes, all synthesizing protein in the same direction: reading the mRNA from 5’ to 3’ and synthesizing the polypeptide from the N terminus to the C terminus. The complete mRNA/poly-ribosome structure is called a polysome.
mRNAs are read three base pairs at a time (codon), and the reading frame will start with the first AUG (figures 11.6 and 11.7). Translation requires the formation of an aminoacyl-tRNA where tRNA is charged with the correct amino acid and brought to the translational machinery. Through the process of tRNA “charging,” each tRNA molecule is linked to its correct amino acid by one of a group of enzymes called aminoacyl tRNA synthetases.

At least one type of aminoacyl tRNA synthetase exists for each of the twenty amino acids; the exact number of
aminoacyl tRNA synthetases varies by species. These enzymes first bind and hydrolyze ATP to catalyze a high-energy bond between an amino acid and adenosine monophosphate (AMP). The activated amino acid is then transferred to the tRNA, and AMP is released. The term “charging” is appropriate, since the high-energy bond that attaches an amino acid to its tRNA is later used to drive the formation of the peptide bond. Each tRNA is named for its amino acid.

### Translational initiation

Translation is initiated by the assembly of the small ribosomal subunit (40S) with initiation factors (IF), which recognize the 5′ cap of the mRNA. This is referred to as the cap-binding complex, and this will scan the mRNA for the initial AUG needed to start translation. Once at the cap, the initiation complex tracks along the mRNA in the 5′ to 3′ direction, searching for the AUG start codon. Many eukaryotic mRNAs are translated from the first AUG, but this is not always the case. Once the appropriate AUG is identified, the other proteins and CBP dissociate, and the 60S subunit binds to the complex of Met-tRNAi, mRNA, and the 40S subunit. This step completes the initiation of translation in eukaryotes (figure 11.8).
Translation elongation

The ribosome has three locations for tRNA binding: A, P, and E sites.

- All tRNAs enter into the A site except for the initial methionine tRNA, which binds to the P site.
- The initial tRNA carrying methionine will attach to the ribosomal P site, and GTP is hydrolyzed, leading to the release of IF factors and recruitment of the large ribosomal subunit forming the complete ribosome.
- All tRNAs exit the ribosome through the E site.

Translation elongation requires energy in the form of GTP, and additional elongation factors (EFs) are required for this process. Elongation proceeds with charged tRNAs sequentially entering and leaving the ribosome as each new amino acid is added to the polypeptide chain. Movement of a tRNA from A to P to E sites is induced by conformational changes that advance the ribosome by three bases in the 3’ direction. GTP energy is required both for the binding of a new aminoacyl-tRNA to the A site and for its translocation to the P site after formation of the peptide bond.

Peptide bonds form between the amino group of the amino acid attached to the A-site tRNA and the carboxyl group of the amino acid attached to the P-site tRNA. A new tRNA with the corresponding amino acid coded for by the mRNA will enter into the A site of the ribosome.

The amino acid attached to the tRNA in the P site will be transferred to the tRNA in the A site; this is referred to as the peptidyl transferase reaction. The tRNAs will slide such that the tRNA in the P site will move to the E site and the tRNA in the A site will move to the P site. The tRNA in the E site will be released, and a new tRNA will enter into the A site, and the process will continue with the addition of tRNAs in the manner until the full message is transcribed (figure 11.8).

Translational termination

Termination of translation occurs when a nonsense codon (UAA, UAG, or UGA) is encountered. Upon aligning with the A site, these nonsense codons are recognized by protein release factors that resemble tRNAs.

The release factors in both prokaryotes and eukaryotes instruct peptidyl transferase to add a water molecule to the carboxyl end of the P-site amino acid. This reaction forces the P-site amino acid to detach from its tRNA, and the newly made protein is released.

The small and large ribosomal subunits dissociate from the mRNA and from each other; they are recruited almost immediately into another translation initiation complex. After many ribosomes have completed translation, the mRNA is degraded so the nucleotides can be reused in another transcription reaction.

References and resources

Text

Clark, M. A. *Biology*, 2nd ed. Houston, TX: OpenStax College, Rice University, 2018, Chapter 15: Genes and Proteins.


**Figures**

Grey, Kindred, Figure 11.6 Genetic code, each codon is 3 nucleotides corresponding to a specific amino acid. The code is degenerate meaning several codes are present for the same amino acid and the codes for similar amino acids are clustered. 2021. [https://archive.org/details/11.6_20210926](https://archive.org/details/11.6_20210926). CC BY 4.0.

Grey, Kindred, Figure 11.7: Summary of translational initiation. 2021. [CC BY SA 3.0](https://creativecommons.org/licenses/by-sa/3.0). Adapted from Eukaryotic Translation Initiation by Chewie. [CC BY SA 3.0](https://creativecommons.org/licenses/by-sa/3.0). From [Wikimedia Commons](https://commons.wikimedia.org).

Grey, Kindred, Figure 11.8 Summary of translational elongation. 2021. [CC BY 4.0](https://creativecommons.org/licenses/by/4.0).