# Biochemistry

**Unit 4 · Lesson 3 · Types of RNA and water-soluble vitamins**

The notes for Lesson 3 of Unit 4: chapters 4.5 to 4.6 of the unit book, with their figures, worked examples, exam traps and quizzes, in one file. The full unit book, with every chapter, the exam question bank and the glossary, is linked at the end.

Lesson 3 of 4 | 2 chapters | Chapters 4.5 to 4.6

## About these notes

These are the notes for **Lesson 3 · Types of RNA and water-soluble vitamins** of the University free n easy video lessons on Biochemistry Unit 4, Nucleic Acids, Vitamins and Minerals. They are chapters 4.5 to 4.6 of the unit book, unchanged, so a page here is the same page in the full book.

## 4.5 Types of RNA: mRNA, tRNA and rRNA

RNA is the working copy of genetic information. It is a single strand made with ribose and uracil, and it folds back on itself into hairpins and loops. Three kinds of RNA build every protein: **messenger RNA** carries the gene's message, **transfer RNA** brings the matching amino acid, and **ribosomal RNA** forms the core of the ribosome and actually joins the amino acids.

You need: ribose, uracil and the phosphodiester bond from Chapter 4.2; base pairing from Chapter 4.3.

### How RNA differs from DNA

- **Sugar and base:** ribose instead of deoxyribose, uracil instead of thymine.
- **Strands:** usually a single strand that pairs with itself in short stretches (A–U, G–C, and also G–U "wobble" pairs), giving A-form hairpins (Chapter 4.4). Chargaff's rules do not apply.
- **Stability:** broken down by alkali and by many ribonucleases; most RNAs live minutes to hours, not a lifetime.
- **Catalysis:** some RNAs are enzymes, called **ribozymes**.

In a typical cell, rRNA is by far the most abundant (roughly 80% of total RNA), tRNA comes next (about 15%) and mRNA is a small fraction (about 5%), although mRNA has the most different

sequences.

## Messenger RNA (mRNA)

mRNA is copied from a gene by RNA polymerase and is read by the ribosome three bases at a time; each triplet is a **codon**. Reading starts at the start codon AUG and ends at a stop codon (UAA, UAG or UGA).

- **Prokaryotic mRNA** is often *polycistronic* (one mRNA codes for several proteins), has no cap or long poly(A) tail, and has a ribosome-binding **Shine–Dalgarno sequence** a few bases before each start codon. It is translated while still being made.
- **Eukaryotic mRNA** is usually *monocistronic*. It is made as a longer precursor (pre-mRNA, also called hnRNA) whose introns are removed by splicing. The finished molecule has a **5′ cap** of 7-methylguanosine joined through an unusual 5′–5′ triphosphate bridge, a 5′ untranslated region (UTR), the coding region, a 3′ UTR, and a **poly(A) tail** of tens to a few hundred adenylates. The cap and tail protect the mRNA from exonucleases and help ribosomes start translation.

## Transfer RNA (tRNA)

tRNA is the adaptor between a codon and an amino acid. Each tRNA is small, about 73–93 nucleotides, and is rich in modified bases (Chapter 4.1). Drawn flat, it looks like a cloverleaf with four arms; in three dimensions the arms stack into an **L shape**, with the anticodon at one end and the amino-acid site at the other.

1. **Acceptor stem:** the paired 5′ and 3′ ends. The 3′ end always finishes in **CCA**; the amino acid is attached to the terminal A by an ester bond, made by an aminoacyl-tRNA synthetase.
2. **D arm:** its loop contains dihydrouridine; it helps the tRNA fold.
3. **Anticodon arm:** its loop carries the three-base **anticodon**, which pairs antiparallel with the mRNA codon. The first anticodon base (5′ end) can “wobble”, so one tRNA can read more than one codon; inosine in that position pairs with U, C or A.
4. **Variable arm:** its length differs between tRNAs.
5. **TψC arm:** named for ribothymidine, pseudouridine and cytidine in its loop; it helps the tRNA bind the ribosome.

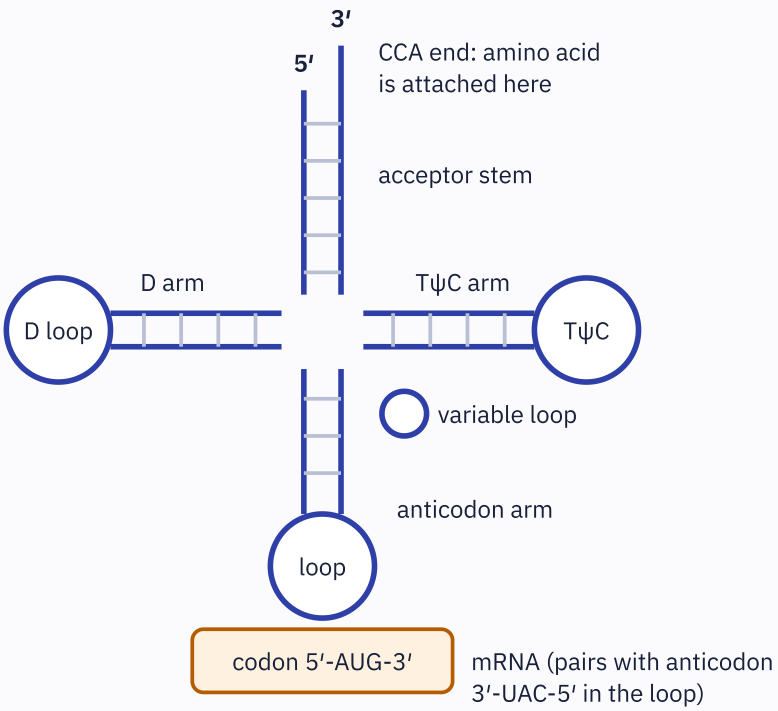



**Figure 4.5.1** The tRNA cloverleaf. Grey rungs are paired bases in the stems; circles are unpaired loops. Notice the two business ends: the CCA 3′ end that carries the amino acid, and the anticodon loop that reads the mRNA codon.

## Ribosomal RNA (rRNA)

A ribosome is two subunits, each made of rRNA and proteins. Their sizes are given in Svedberg units (S), which measure how fast a particle sediments in a centrifuge. Because sedimentation depends on shape as well as mass, S values do not add.

| RIBOSOME | SMALL SUBUNIT | LARGE SUBUNIT |
|---|---|---|
| Prokaryotic 70S | 30S: 16S rRNA + 21 proteins | 50S: 23S and 5S rRNA + over 30 proteins |
| Eukaryotic 80S (cytoplasm) | 40S: 18S rRNA + proteins | 60S: 28S (in mammals), 5.8S and 5S rRNA + proteins |

rRNA is not just scaffolding. The 16S rRNA pairs with the Shine–Dalgarno sequence to place the start codon, and the 23S rRNA of the large subunit catalyses peptide-bond formation: the **peptidyl transferase** centre is made of RNA, so the ribosome is a ribozyme.

## Other RNAs, in one line each

snRNA splices pre-mRNA; snoRNA guides chemical modification of rRNA; microRNA (miRNA) and small interfering RNA (siRNA) switch genes off by pairing with mRNA; long non-coding RNAs

regulate chromatin and transcription. These are covered in molecular biology courses.

### WORKED EXAMPLE

**Question (6 marks).** An mRNA reads 5′-AUG UUC GGA UAA-3′. (a) How many amino acids does it code for, and which? (b) Write the anticodon of each tRNA used, 5′ → 3′. (c) Write the DNA template strand, 5′ → 3′.

1. (a) Codons: AUG (Met), UUC (Phe), GGA (Gly), UAA (stop). So **3 amino acids**: Met–Phe–Gly. A stop codon has no tRNA; a release factor reads it.
2. (b) Anticodons pair antiparallel. AUG ↔ 3′-UAC-5′ = **5′-CAU-3′**; UUC ↔ 3′-AAG-5′ = **5′-GAA-3′**; GGA ↔ 3′-CCU-5′ = **5′-UCC-3′**.
3. (c) The template is complementary to the mRNA, with T for U: 3′-TAC AAG CCT ATT-5′, which written 5′ → 3′ is **5′-TTATCCGAACAT-3′**. The coding strand has the mRNA sequence with T: 5′-ATGTTCGGATAA-3′.

### EXAM TRAPS

- 30S + 50S makes 70S, not 80S; Svedberg values are not additive.
- The amino acid attaches to the 3′ CCA end of tRNA, not to the anticodon.
- Write anticodons 5′ → 3′ unless the question shows the direction; AUG's anticodon is 5′-CAU-3′, not 5′-UAC-3′.
- Cap and poly(A) tail belong to eukaryotic mRNA; prokaryotic mRNA has a Shine–Dalgarno sequence instead.
- rRNA is the most abundant RNA, mRNA the least; but mRNA is the most varied.

### CHECK YOURSELF

– REMEMBER **Name the four arms of the tRNA cloverleaf.** 2 marks

Acceptor stem, D arm, anticodon arm, TψC arm (plus a variable arm/loop).

– REMEMBER **Which rRNAs are in the prokaryotic 50S subunit?** 1 mark

23S and 5S rRNA.

– UNDERSTAND **What are the functions of the 5′ cap and poly(A) tail?** 3 marks

Both protect the mRNA from exonucleases; the cap is recognised when translation starts and the tail helps it, so they raise the stability and translation of the mRNA. The cap also helps export from the nucleus.

– UNDERSTAND **Why is the ribosome called a ribozyme?** 2 marks

Peptide bonds are formed at the peptidyl transferase centre, which is made of rRNA (23S in bacteria), not protein. So the catalyst is RNA.

– APPLY **A tRNA has the anticodon 5′-GAA-3′. Which codon does it read?** 1 mark

Pair antiparallel: codon **5′-UUC-3′** (Phe).

– APPLY **An mRNA codes for a 150-amino-acid protein. Find the minimum number of nucleotides in its coding region including the stop codon.** 2 marks

(150 + 1) × 3 = **453 nucleotides**.

– ANALYZE **A cell contains about 80% rRNA but thousands of different mRNAs make up only about 5%. Explain both facts.** 4 marks

A cell needs very many ribosomes, all with the same few rRNAs, so rRNA mass is large. Each gene makes its own mRNA, so mRNA has many sequences, but each is short-lived and present in few copies, so its total mass is small.

BEYOND THE SYLLABUS

mRNA vaccines deliver a capped, poly(A)-tailed, chemically modified mRNA in lipid nanoparticles so that cells make a viral protein for a while. Cryo-electron microscopy now shows ribosomes and spliceosomes at near-atomic detail. Sequencing of 16S rRNA genes is the standard way to identify bacteria and to profile the gut microbiome, which links this chapter to microbiology. Search “16S rRNA sequencing” and “mRNA vaccine design”. This is not for the exam.

## 4.6 Water-soluble vitamins: B complex and C

A **vitamin** is an organic compound the body needs in small amounts but cannot make in enough quantity, so it must come from food. The water-soluble vitamins are the eight B

vitamins and vitamin C. Almost every B vitamin is turned into a **coenzyme**, a small helper molecule that an enzyme needs to do its chemistry. Learn each vitamin as a chain: vitamin → coenzyme → reaction type → deficiency disease. That chain is what examiners ask for.

You need: the nucleotide coenzymes $NAD^+$, FAD and CoA from Chapter 4.2. The pathways where these coenzymes work are in Unit 5 (Bioenergetics and carbohydrate metabolism).

## Common features

- They dissolve in water, are absorbed directly into blood, and any excess is mostly lost in urine. So the body stores little of them and needs a regular supply. Vitamin B12 is the exception: the liver stores enough for years.
- Many are lost in cooking water, and some are destroyed by heat (vitamin C, thiamine) or light (riboflavin).
- Toxicity is uncommon, because the excess is excreted.

## The B vitamins and vitamin C, vitamin by vitamin

| VITAMIN | ACTIVE (COENZYME) FORM | WHAT IT DOES | DEFICIENCY |
|---|---|---|---|
| **B1** thiamine | Thiamine pyrophosphate (TPP) | Oxidative decarboxylation of α-keto acids (pyruvate dehydrogenase, α-ketoglutarate dehydrogenase); transketolase of the pentose phosphate pathway | Beriberi (dry: nerve damage; wet: heart failure and oedema); Wernicke–Korsakoff syndrome in alcoholism |
| **B2** riboflavin | FMN, FAD | Carry two hydrogens in redox reactions (succinate dehydrogenase, Complex I) | Angular stomatitis, cheilosis, glossitis |
| **B3** niacin (nicotinic acid, nicotinamide) | $NAD^+$, $NADP^+$ | Carry a hydride ion in dehydrogenase reactions; NADPH for biosynthesis | Pellagra: dermatitis, diarrhoea, dementia, and death if untreated |
| **B5** pantothenic acid | Coenzyme A; acyl carrier protein | Carry acyl groups through a thiol (–SH) end, as in acetyl-CoA | Rare; “burning feet” syndrome |

| VITAMIN | ACTIVE (COENZYME) FORM | WHAT IT DOES | DEFICIENCY |
|---|---|---|---|
| **B6** pyridoxine, pyridoxal, pyridoxamine | Pyridoxal phosphate (PLP) | Amino acid reactions: transamination, decarboxylation (making GABA, serotonin, histamine); haem synthesis; glycogen phosphorylase | Peripheral neuropathy, convulsions in infants, microcytic anaemia; caused by the TB drug isoniazid |
| **B7** biotin | Biotin bound to a lysine of the enzyme | Carries $CO_2$ in carboxylases (pyruvate carboxylase, acetyl-CoA carboxylase, propionyl-CoA carboxylase) | Rare; dermatitis and hair loss; induced by eating much raw egg white (avidin binds biotin) |
| **B9** folic acid | Tetrahydrofolate (THF) | Carries one-carbon units (formyl, methylene, methyl) for purine synthesis and for making dTMP | Megaloblastic anaemia; neural tube defects in the baby if low in early pregnancy |
| **B12** cobalamin (contains cobalt) | Methylcobalamin; 5′-deoxyadenosylcobalamin | Methionine synthase (homocysteine → methionine, freeing THF); methylmalonyl-CoA mutase (→ succinyl-CoA) | Megaloblastic anaemia with nerve damage; pernicious anaemia when intrinsic factor is missing |
| **C** ascorbic acid | Ascorbate itself (a reducing agent) | Keeps the iron of prolyl and lysyl hydroxylases reduced, so collagen is hydroxylated; antioxidant; helps absorb dietary iron | Scurvy: bleeding gums, poor wound healing, bleeding under the skin |

## Four links examiners like

1. **One enzyme, many vitamins.** The pyruvate dehydrogenase complex, which joins glycolysis to the citric acid cycle, needs TPP (B1), lipoic acid, CoA (B5), FAD (B2) and $NAD^+$ (B3). So a shortage of thiamine first harms tissues that burn glucose fastest: nerves and heart (Figure 4.6.1).
2. **Niacin from tryptophan.** The body can make niacin from the amino acid tryptophan, roughly 1 mg of niacin from 60 mg of tryptophan, which is why intake is counted in **niacin equivalents**. Pellagra appeared in people living mostly on maize, whose niacin is bound and poorly available, and has been linked in India to diets based on jowar (sorghum), which is rich in leucine.

3. **Folate and B12 work together.** Methionine synthase moves a methyl group from $N^5$-methyl-THF to homocysteine using methylcobalamin. Without B12, folate is "trapped" as methyl-THF, DNA synthesis slows, and both deficiencies give the same large, immature red cells (megaloblastic anaemia). Only B12 deficiency also damages nerves. B12 is made only by microbes and comes from animal foods, so strict vegetarians, common in India, are at risk; it is absorbed in the ileum only when bound to intrinsic factor from the stomach.

4. **Vitamin C and collagen.** Humans, unlike most animals, cannot make ascorbic acid, because they lack the enzyme L-gulonolactone oxidase. Without it, prolyl hydroxylase cannot keep working, collagen triple helices are weak, and blood vessels and gums bleed. Amla (Indian gooseberry), guava and citrus are rich sources.

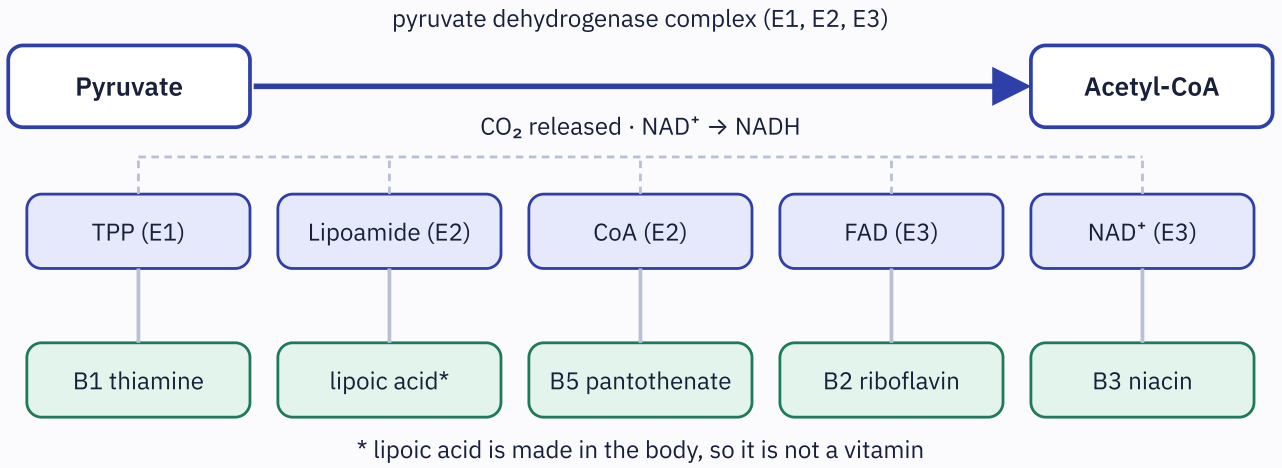



**Figure 4.6.1** One reaction, four B vitamins. The coenzymes (blue) of the pyruvate dehydrogenase complex each come from a vitamin (green). A shortage of any of B1, B2, B3 or B5 slows the conversion of pyruvate to acetyl-CoA; that is why thiamine deficiency raises blood pyruvate and lactate.

## WORKED EXAMPLE

**Question (6 marks).** (a) A day's diet supplies 9 mg of preformed niacin and 780 mg of tryptophan. Taking 60 mg tryptophan = 1 mg niacin, find the niacin equivalents (NE). (b) A 45-year-old strict vegetarian has tiredness, tingling in the feet, large red cells on a blood smear and raised methylmalonic acid in urine. Which vitamin is deficient? Give the reasoning.

1. (a) Niacin from tryptophan = 780 ÷ 60 = 13 mg.
2. NE = preformed niacin + niacin from tryptophan = 9 + 13 = **22 mg NE per day**.
3. (b) Large red cells (megaloblastic anaemia) point to folate or B12 deficiency.
4. Nerve symptoms and raised methylmalonic acid point to B12 only: methylmalonyl-CoA mutase needs adenosylcobalamin, so methylmalonyl-CoA builds up and is excreted as methylmalonic acid.
5. A strict vegetarian diet lacks B12. Answer: **vitamin B12 (cobalamin) deficiency**. Giving folate alone would improve the blood picture but not stop the nerve damage, which is why B12 must be checked.

## EXAM TRAPS

- Thiamine coenzyme is TPP; pyridoxine coenzyme is PLP. Do not swap the two "P" coenzymes.
- Pellagra is niacin (B3); beriberi is thiamine (B1); scurvy is vitamin C. Write the 3 Ds for pellagra.
- Both folate and B12 deficiency cause megaloblastic anaemia; only B12 deficiency causes nerve damage and methylmalonic aciduria.
- Biotin carries $CO_2$ (carboxylation); TPP takes part in decarboxylation. Opposite jobs, similar words.
- B12 contains cobalt; it is the only vitamin with a metal.

## CHECK YOURSELF

– REMEMBER **Give the coenzyme form of riboflavin, niacin and pantothenic acid.** 3 marks

Riboflavin: FMN and FAD. Niacin: $NAD^+$ and $NADP^+$. Pantothenic acid: coenzyme A (and the acyl carrier protein).

– REMEMBER **Name the deficiency disease of thiamine and of vitamin C.** 1 mark

Thiamine: beriberi. Vitamin C: scurvy.

– UNDERSTAND **Why are water-soluble vitamins needed regularly while vitamin A is not?** 2 marks

Water-soluble vitamins are stored little and the excess is lost in urine (B12 aside), so stocks run down in weeks. Vitamin A is fat-soluble and stored in the liver for months.

– UNDERSTAND **Explain the "methyl trap" of folate in B12 deficiency.** 3 marks

$N^5$-methyl-THF can give up its methyl only to homocysteine, through B12-dependent methionine synthase. Without B12 folate accumulates as methyl-THF, other THF forms run short, purine and dTMP synthesis slow, and megaloblastic anaemia develops.

– APPLY **A diet gives 6 mg niacin and 600 mg tryptophan. Find the niacin equivalents.** 2 marks

6 + 600/60 = 6 + 10 = **16 mg NE**.

– APPLY **A TB patient on isoniazid develops tingling in the hands and feet. Which vitamin should be given, and why?** 2 marks

Vitamin B6 (pyridoxine). Isoniazid reacts with pyridoxal and lowers PLP, which nerves need for neurotransmitter synthesis.

– ANALYZE **Thiamine deficiency raises blood pyruvate and lactate. Analyse why, using the pathway.** 4 marks

Pyruvate dehydrogenase needs TPP. Without it pyruvate cannot become acetyl-CoA, so pyruvate accumulates, and lactate dehydrogenase turns the excess into lactate. Energy supply to nerves and heart falls, giving the symptoms of beriberi.

BEYOND THE SYLLABUS

Antifolate drugs act on these pathways: methotrexate blocks dihydrofolate reductase in cancer cells, and trimethoprim blocks the bacterial enzyme. Food fortification is a public-health tool; India fortifies rice and salt in some programmes and recommends folic acid around pregnancy to prevent neural tube defects. Riboflavin and B12 are made industrially by microbial fermentation, a direct biotechnology application. Search "vitamin fermentation industrial" and "food fortification India". This is not for the exam.

## Key terms of this lesson

| TERM | MEANING OR FORMULA | CHAPTER |
|---|---|---|
| Ribosomes | 70S = 30S (16S) + 50S (23S, 5S); 80S = 40S (18S) + 60S (28S, 5.8S, 5S) | 4.5 |
| Niacin equivalents | NE (mg) = niacin (mg) + tryptophan (mg) ÷ 60 | 4.6 |

## Glossary (terms used in this lesson)

**Anticodon** Three bases in the tRNA anticodon loop that pair antiparallel with an mRNA codon.

**Chargaff's rules** In double-stranded DNA, A = T and G = C, so purines equal pyrimidines.

**Codon** A triplet of mRNA bases that specifies one amino acid or a stop signal.

**Coenzyme** A small organic molecule, often made from a vitamin, that an enzyme needs to catalyse its reaction.

**Intrinsic factor** A stomach protein needed to absorb vitamin B12 in the ileum.

**Megaloblastic anaemia** Anaemia with large, immature red cells, caused by folate or B12 deficiency.

**Niacin equivalent** 1 mg niacin or 60 mg tryptophan; the unit for total niacin intake.

**Nucleotide** A nucleoside with one or more phosphate groups on the sugar.

**Phosphodiester bond** The phosphate bridge between the 3′-OH of one nucleotide and the 5′-OH of the next.

**Poly(A) tail** The run of adenylates added to the 3′ end of most eukaryotic mRNAs.

**Ribozyme** An RNA molecule that acts as an enzyme, such as the 23S rRNA peptidyl transferase.

## The full unit book

Every chapter of Unit 4, the unit summary, the exam question bank with model answers and the full glossary: Biochemistry · Unit 4 · Nucleic Acids, Vitamins and Minerals (one file, works offline).

## Sources and further reading

### Standard textbooks

- David L. Nelson and Michael M. Cox, *Lehninger Principles of Biochemistry*: the chapters on nucleotides and nucleic acids, and on vitamins as coenzymes (from memory; check the chapter numbers in your edition).
- U. Satyanarayana and U. Chakrapani, *Biochemistry*: the chapters on nucleic acids, vitamins and minerals; widely prescribed in Indian universities (from memory; check).
- Jeremy M. Berg, John L. Tymoczko and Lubert Stryer (later editions with Gregory Gatto), *Biochemistry* (from memory; check).
- Donald Voet and Judith G. Voet, *Biochemistry*: detailed treatment of DNA conformations A, B and Z (from memory; check).

### Open web resources

- Wikipedia, "Nucleic acid double helix", comparison table of A-, B- and Z-DNA geometry: en.wikipedia.org/wiki/Nucleic_acid_double_helix
- NIH Office of Dietary Supplements, "Vitamin A and Carotenoids: Fact Sheet for Health Professionals", for the IU and RAE conversion factors: ods.od.nih.gov/factsheets/VitaminA-HealthProfessional

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