What Is The Potential ATP Yield From Complete Oxidation Of Stearic Acid (18:0)? (Use The P/O Ratio: 1

What Is The Potential ATP Yield From Complete Oxidation Of Stearic Acid (18:0)? (Use The P/O Ratio: 1

Understanding the energy potential stored within fatty acids is fundamental in biochemistry, especially in the context of metabolism and energy production. Among various fatty acids, stearic acid (18:0), a saturated long-chain fatty acid with 18 carbon atoms, plays a significant role as an energy source in humans and other organisms. This article explores the detailed process of how stearic acid is metabolized via beta-oxidation, the subsequent entry into the citric acid cycle (Krebs cycle), and ultimately, the total ATP yield achievable from its complete oxidation, considering a P/O ratio of 1.

Introduction to Stearic Acid and Its Significance

Stearic acid ($C_{18}H_{36}O_2$) is a common saturated fatty acid found in various dietary fats, notably in animal fats and cocoa butter. As a long-chain fatty acid, it serves as an important energy reservoir. When the body requires energy, fatty acids like stearic acid undergo a series of metabolic processes that lead to the production of ATP, the primary energy currency of cells.

The complete oxidation of fatty acids is highly efficient, yielding significantly more ATP per molecule compared to carbohydrates. Understanding the potential ATP yield from stearic acid provides insight into its role as an energy substrate, especially during fasting, prolonged exercise, or in states of energy deficiency.

Metabolic Pathway Overview for Stearic Acid Oxidation

The process of oxidizing stearic acid involves several key steps:

1. Activation of Stearic Acid
2. Beta-Oxidation Cycle
3. Entry of Acetyl-CoA into the Citric Acid Cycle
4. Electron Transport and ATP Synthesis

Each step contributes to the overall ATP yield, and understanding these individual components is crucial for accurate calculations.

Step 1: Activation of Stearic Acid

Before beta-oxidation can occur, stearic acid must be activated in the cytoplasm:

- Reaction: Stearic acid reacts with Coenzyme A (CoA) to form stearoyl-CoA.
- Enzyme involved: Acyl-CoA synthetase.
- ATP consumption: 2 ATP equivalents are used in the activation process (conversion of ATP to AMP and PPi, which is then hydrolyzed).

This activation step is essential for subsequent mitochondrial beta-oxidation.

Step 2: Beta-Oxidation of Stearic Acid

Beta-oxidation is a cyclic process that shortens the fatty acyl-CoA by two carbons each cycle, producing:

- NADH
- FADH2
- Acetyl-CoA

For stearic acid (C18), the number of beta-oxidation cycles is:

$$
\text{Number of cycles} = \frac{\text{Number of carbons}}{2} - 1 = \frac{18}{2} - 1 = 8
$$

Each cycle of beta-oxidation yields:

- 1 FADH2
- 1 NADH
- 1 Acetyl-CoA

Total from beta-oxidation:

- FADH2: 8 molecules
- NADH: 8 molecules
- Acetyl-CoA: Number of molecules equal to the number of acetyl units produced after complete oxidation:

$$
\text{Number of Acetyl-CoA} = \frac{\text{Number of carbons}}{2} = 9
$$

This includes the initial cleavage step, leading to 9 acetyl-CoA molecules.

Step 3: Entry into the Citric Acid Cycle

Each acetyl-CoA enters the citric acid cycle, where it is further oxidized to produce:

- 3 NADH
- 1 FADH2
- 1 GTP (equivalent to ATP in terms of energy)

for each acetyl-CoA molecule.

Total citric acid cycle outputs:

$$
\begin{aligned}
& \text{NADH} &= 9 \text{ (from beta-oxidation)} + (9 \times 3) = 9 + 27 = 36 \\
& \text{FADH2} &= 8 \text{ (from beta-oxidation)} + (9 \times 1) = 8 + 9 = 17 \\
& \text{ATP (from GTP)} &= 9
\end{aligned}
$$

Step 4: Electron Transport Chain & ATP Calculation (Using P/O Ratio: 1)

The P/O ratio indicates how many ATP molecules are produced per pair of electrons transferred to oxygen. Here, we are assuming a P/O ratio of 1, meaning each NADH or FADH2 yields 1 ATP.

Total ATP from NADH and FADH2:

- NADH: 36 molecules
- FADH2: 17 molecules

Total ATP equivalents:

$$
\text{From NADH} = 36 \times 1 = 36 \text{ ATP}
$$
$$
\text{From FADH2} = 17 \times 1 = 17 \text{ ATP}
$$

Adding the GTP (which is equivalent to ATP):

$$
\text{Total ATP} = 36 + 17 + 9 = 62 \text{ ATP}
$$

Note: The initial activation cost of 2 ATP equivalents must be subtracted:

$$
62 - 2 = 60 \text{ ATP}
$$

Final Calculation: Total Potential ATP Yield from Complete Oxidation of Stearic Acid

Summary:

Step	Molecules Produced	ATP Yield (using P/O = 1)
Activation	2 ATP (cost)	-2 ATP
Beta-oxidation	8 FADH2, 8 NADH, 9 Acetyl-CoA	-
Citric Acid Cycle	36 NADH, 17 FADH2, 9 GTP	+62 ATP

Total ATP:

$$
\boxed{
\textbf{Approximately 60 ATP molecules} \text{ per molecule of stearic acid}
}
$$

Implications and Significance of the ATP Yield

The high ATP yield from stearic acid underscores the efficiency of fatty acids as energy sources. Compared to carbohydrates like glucose, which yields approximately 30-32 ATP per molecule, fatty acids like stearic acid provide nearly double the energy per molecule. This is why fats are the primary energy storage molecules in humans.

Furthermore, understanding the ATP yield helps in clinical and nutritional contexts, such as:

- Evaluating energy deficits in fasting or starvation.
- Designing diets for athletes or individuals with metabolic disorders.

- Understanding the bioenergetics of lipid metabolism.

Conclusion

The complete oxidation of stearic acid (18:0) through beta-oxidation, citric acid cycle, and electron transport chain yields approximately 60 ATP molecules when assuming a P/O ratio of 1. This high energy yield highlights the importance of fatty acids as dense energy reserves. Recognizing the steps involved and their energetic contributions provides a comprehensive understanding of lipid metabolism and its significance in cellular bioenergetics.

References and Further Reading

- Nelson, D. L., & Cox, M. M. (2017). Lehninger Principles of Biochemistry. 7th Edition. W.H. Freeman.
- Berg, J. M., Tymoczko, J. L., Gatto, G. J., & Stryer, L. (2015). Biochemistry. 8th Edition. W.H. Freeman.
- Vander, A. J., Sherman, J. H., & Luciano, D. (2014). Human Physiology: The Mechanisms of Body Function. McGraw-Hill Education.

Note: Actual ATP yields can vary depending on cellular conditions and the P/O ratio, which is often considered to be around 2.5 for NADH and 1.5 for FADH2 in mammalian mitochondria. However, this calculation assumes a P/O ratio of 1 for simplicity and standardization in energy estimation.

Frequently Asked Questions

What is the molecular structure of stearic acid (18:0)?

Stearic acid is a saturated fatty acid with an 18-carbon chain and no double bonds, represented as CH3(CH2)16COOH.

How is the complete oxidation of stearic acid (18:0) carried out in the body?

It involves beta-oxidation in the mitochondria, producing acetyl-CoA molecules, which then enter the citric acid cycle for further oxidation.

What is the total number of acetyl-CoA molecules produced

from one molecule of stearic acid?

Eight acetyl-CoA molecules are generated from the complete beta-oxidation of one stearic acid molecule.

How do you calculate the ATP yield from the oxidation of stearic acid using the P/O ratio of 1?

By multiplying the total number of ATP molecules generated per acetyl-CoA by the number of acetyl-CoA molecules, then accounting for initial activation costs, with the P/O ratio of 1 indicating 1 ATP per NADH or FADH2 oxidized.

What is the approximate total ATP yield from the complete oxidation of stearic acid (18:0) using a P/O ratio of 1?

Approximately 129 ATP molecules are produced from one molecule of stearic acid during complete oxidation.

Why is the P/O ratio important in calculating ATP yield in fatty acid oxidation?

The P/O ratio indicates the number of ATP molecules generated per oxygen atom reduced, helping estimate total ATP production during oxidative phosphorylation.

How does the saturation of stearic acid influence its ATP yield compared to unsaturated fatty acids?

Saturated fatty acids like stearic acid undergo straightforward beta-oxidation without additional steps, typically resulting in higher ATP yields compared to unsaturated fatty acids, which may require auxiliary enzymes and pathways.

What are the clinical implications of understanding ATP yield from fatty acids like stearic acid?

Knowing ATP yields helps in understanding energy metabolism, diagnosing metabolic disorders, and designing nutritional strategies for conditions like fasting, obesity, and fatty acid oxidation defects.

Additional Resources

What Is The Potential ATP Yield From Complete Oxidation Of Stearic Acid (18:0)?

Understanding the energetic yield of fatty acids is fundamental to biochemistry, physiology, and metabolic research. Among the myriad fatty acids, stearic acid (octadecanoic acid, 18:0) stands out as a common saturated long-chain fatty acid prevalent in dietary fats and biological tissues. Determining its potential ATP yield from complete oxidation offers insights into metabolic efficiency, energy production, and nutritional implications. This detailed review explores the biochemical pathways involved, the theoretical calculations based on the P/O ratio, and the significance of these numbers in health and disease contexts.

Introduction

Fatty acids serve as major energy reservoirs in living organisms. Their oxidation provides more ATP per molecule than carbohydrates, making them an efficient energy source. Stearic acid, a saturated 18-carbon fatty acid, is extensively studied because of its prevalence in dietary fats, especially in animal fats and cocoa butter. Its complete oxidation involves multiple steps—activation, β-oxidation, the citric acid cycle, and oxidative phosphorylation—culminating in ATP production.

The primary goal of this review is to estimate the potential ATP yield from the complete oxidation of stearic acid, assuming a P/O ratio of 1, which indicates that one molecule of ATP is synthesized per atom of oxygen reduced. This assumption simplifies calculations and is often used in theoretical estimations, although actual in vivo yields may vary.

Biochemical Pathways of Stearic Acid Oxidation

Understanding the pathway is essential for calculating ATP yield accurately.

Activation of Stearic Acid

Before oxidation, stearic acid must be activated in the cytoplasm:
- Stearic acid reacts with Coenzyme A (CoA) to form stearoyl-CoA.
- Catalyzed by acyl-CoA synthetase.
- Consumes 2 ATP equivalents (technically, 2 high-energy bonds, equivalent to 2 ATP).

Transport into Mitochondria

- Stearoyl-CoA is transported into the mitochondrial matrix.
- Via the carnitine shuttle, involving carnitine palmitoyltransferase I and II.
- This transport does not consume ATP but is critical for subsequent oxidation.

β-Oxidation Pathway

- Repeated cycles cleave two-carbon units as acetyl-CoA.
- Each cycle shortens the acyl-CoA by two carbons.
- For stearic acid (18 carbons), the number of cycles: (18/2) - 1 = 8 cycles.

Production of Acetyl-CoA and FADH2/NADH

- Each cycle produces:
- 1 NADH
- 1 FADH2
- 1 Acetyl-CoA (except the last cycle, which yields two acetyl-CoA molecules)
- The final thiolysis yields 9 acetyl-CoA molecules (since 18 carbons / 2).

Entry into the Citric Acid Cycle

- Each acetyl-CoA enters the TCA cycle:
- Produces 3 NADH, 1 FADH2, and 1 GTP (equivalent to ATP).

Calculating Theoretical ATP Yield

Theoretically, the total ATP generated depends on the number of NADH and FADH2 molecules produced, as these are substrates for oxidative phosphorylation.

Step 1: ATP from β-Oxidation

- Each cycle yields:
- 1 NADH
- 1 FADH2
- Total cycles: 8
- Total NADH: 8
- Total FADH2: 8

Step 2: ATP from the TCA Cycle

- Each acetyl-CoA yields:
- 3 NADH
- 1 FADH2
- 1 GTP (ATP)

- Total acetyl-CoA molecules: 9

- Total TCA outputs:
- NADH: $9 \times 3 = 27$
- FADH2: $9 \times 1 = 9$
- ATP/GTP: 9

Step 3: Total NADH and FADH2

- NADH total: 8 (from β-oxidation) + 27 (from TCA) = 35
- FADH2 total: 8 (from β-oxidation) + 9 (from TCA) = 17

Step 4: Calculating ATP Yield with P/O Ratio of 1

- Each NADH: 1 ATP (by assumption)
- Each FADH2: 1 ATP

Total ATP from NADH:
- 35 ATP

Total ATP from FADH2:
- 17 ATP

Total ATP from GTP/ATP:
- 9 ATP

Step 5: Subtract Activation Cost

- Activation of stearic acid consumes 2 high-energy bonds (equivalent to 2 ATP).

Final Calculation:

- Total ATP produced:
- From NADH: 35
- From FADH2: 17
- From GTP: 9
- Subtract activation cost: 2

Total ATP = 35 + 17 + 9 - 2 = 59 ATP molecules

Additional Considerations and Assumptions

While the above calculation provides a theoretical maximum, several factors influence actual yields:

- Transport and Activation Efficiency: The energy cost of transporting fatty acids into mitochondria and activating them may vary.
- P/O Ratio Variability: The assumption of a P/O ratio of 1 simplifies calculations but actual mitochondrial efficiency often ranges between 2 to 3 for NADH and FADH2, respectively.
- Incomplete Oxidation and Coupling Efficiency: In vivo, some energy is lost as heat or used for other cellular processes.
- Peroxisomal β-oxidation: In certain tissues, very long-chain fatty acids like stearic acid may initially

undergo peroxisomal oxidation, which yields fewer ATP molecules.

Comparison with Other Fatty Acids

Stearic acid's ATP yield can be contrasted with other fatty acids:

Fatty Acid	Carbon Chain Length	Estimated ATP (with P/O=1)	Notes
Palmitic acid (16:0)	16	~106	Commonly studied; slightly less than stearic acid due to shorter chain
Oleic acid (18:1)	18	Slightly less than stearic acid, due to double bond presence	Double bonds influence oxidation efficiency
Stearic acid (18:0)	18	~59	Fully saturated, maximum oxidation potential

This comparison highlights how chain length and saturation influence energetic yield.

Physiological Significance and Implications

Understanding the ATP yield from fatty acids like stearic acid is critical in contexts such as:

- Energy metabolism during fasting or starvation: Fatty acids become primary energy sources.
- Obesity and metabolic disorders: Fatty acid oxidation efficiency influences energy balance.
- Pharmacological interventions: Drugs targeting fatty acid oxidation pathways can modulate energy expenditure.
- Dietary considerations: The energetic contribution of different dietary fats varies based on their fatty acid composition.

Conclusion

The complete oxidation of stearic acid (18:0) theoretically yields approximately 59 ATP molecules per molecule of fatty acid when assuming a P/O ratio of 1. This calculation underscores the high energy density of long-chain saturated fatty acids, making them potent sources of metabolic energy. However, in vivo yields are subject to mitochondrial efficiency, cellular regulation, and physiological conditions. These estimations serve as valuable benchmarks in biochemistry, nutrition, and medical research, deepening our understanding of lipid metabolism's energetics.

References

- Berg, J. M., Tymoczko, J. L., Gatto, G. J., & Stryer, L. (2015). Biochemistry (8th ed.). W. H. Freeman and Company.
- Nelson, D. L., & Cox, M. M. (2017). Lehninger Principles of Biochemistry (7th ed.). W. H. Freeman.
- Houten, S. M., & Wanders, R. J. (2010). A General Introduction to the Biochemistry of Mitochondrial Fatty Acid β-Oxidation. Journal of Inherited Metabolic Disease, 33(5), 469–477.
- McGarry, J. D., & Foster, D. W. (1980). Regulation of Fatty Acid Oxidation and Ketogenesis. Annual Review of Biochemistry, 49, 395–420.

Note: The ATP yield values are approximate and based on simplified assumptions. Actual mitochondrial efficiency and cellular conditions can significantly influence the real energy output.

What Is The Potential Atp Yield From Complete Oxidation Of Stearic Acid 18 0 Use The P O Ratio 1

What Is The Potential Atp Yield From Complete Oxidation Of Stearic Acid 18 0 Use The P O Ratio 1

Related Articles

- 1. Two Polygons Are Similar. If One Side Of The First Polygon Is Twice The Length Of The Corresponding
- Which Data Description Techniques Are NOT Appropriate For Visualizing An Attribute 'Hair Length' That
- - Why Did Some Critics And Parents Complain About Maurice Sendak's Book Where The Wild Things Are When

Back to Home