N6-methyladenosine Modification in Bacterial mRNA

Ruxia Gao1*, Heng Shi2*, Yingchao Zhang1, Xiaolong Shao2 and Xin Deng2*

1College of Life Science, Shantou University, Shantou, China
2Key Laboratory of Molecular Microbiology and Technology, Ministry of Education, TEDA Institute of Biological Sciences and Biotechnology, Nankai University, 23 Hongda Street, Tianjin, China

*Corresponding author: Dr. Xin Deng, TEDA Institute of Biological Sciences and Biotechnology, Nankai University, 23 Hongda Street, Tianjin 300457, China, E-mail: dengxin@nankai.edu.cn

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Abstract

Among more than 140 naturally occurring RNA modifications have been identified, N6-methyladenosine (m6A) is the most abundant messenger RNA (mRNA) modification in eukaryotic organisms. A group of demethylases, methyltransferase and m6A-specific binding proteins in mammals, plants as well as yeast are in support of the regulatory functions of this RNA modification. Recent years, with the fast development of purification methods and detecting techniques, researchers have extended the range of RNA epigenetics from the rRNA and tRNA modification to the field of mRNA and ncRNA in eukaryotes. However, we have little understanding of m6A modification in bacteria RNA, particularly mRNA. This review summarizes the recent research advances of eukaryotic m6A modification, and outlines the optimized analysis techniques together with recent progress on m6A modification in bacterial mRNA.

Keywords: N6-methyladenosine; mRNA; Bacteria

Introduction

Among more than 140 naturally occurring RNA modifications have been identified [1], N6-methyladenosine (m6A) is the most abundant messenger RNA (mRNA) modification in eukaryotic organisms. A group of demethylases, methyltransferase and m6A-specific binding proteins in mammals, plants as well as yeast are in support of the regulatory functions of this RNA modification. Recent years, with the fast development of purification methods and detecting techniques, researchers have extended the range of RNA epigenetics from the rRNA and tRNA modification to the field of mRNA and ncRNA in eukaryotes [2].

However, we have little understanding of m6A modification in bacteria RNA, particularly mRNA. This review summarizes the recent research advances of eukaryotic m6A modification, and outlines the optimized analysis techniques together with recent progress on m6A modification in bacterial mRNA.

The study of RNA modifications dates back to early 1950s, when Srinivasan et al. firstly found rRNA and tRNA methylation in bacteria [3-6]. In 1970s, Greenberg et al. pioneered a new research field on the methylation of rRNA and tRNA in animal cells [6-9]. Over the last two decades, m6A became the most important modification in eukaryotes, thanks to the identification of a group of m6A-associated proteins, including METTL3, METTL14, FTO and ALKBH5 [10-14]. METTL3 and METTL14 form a heterodimer that catalyzes m6A RNA methylation, while WTAP (Wilms tumor 1 associated protein) interacts with the complex and affects the mRNA methylation [15].

FTO and ALKBH5 are m6A RNA demethylases, which are involved in development, RNA metabolism and fertility [11,16]. Moreover, two m6A-specific binding proteins (YTHDF2 and YTHDF1) have been discovered and characterized, suggesting its important roles in mRNA stability and translation efficiency [17,18]. A recent report has revealed the structural basis of N6-adenosinemethylation by the METTL3-METTL14 complex for the first time, which demonstrates the molecular basis of the m6A methylase reaction [19].

Although fast and exciting breakthroughs have been made on m6A in eukaryotic mRNA, very little is known on m6A in bacterial RNA. This review focuses on the bacterial m6A modification (especially in mRNA), research methods, and key discoveries of this modification to promote intensive study in this field.

Methods of Detection

Initially, researchers employed a radioactive isotope labeling method (labelled by incorporation of 32P-orthophosphate and either H or 14C-(methyl)-methionine) to detects m6A modification in RNA [20]. Later, the subsequent approach of primer extension assay was used for the detection of chemical modification of m6G, m5A, m5G, and pseudouridine [21]. However, m6A modification of RNA does not interfere the reverse transcription, thus primer extension assay cannot detect the methylation of m6A [21].

The continuous optimization of m6A-seq or MeRIP-seq technology (A combination of anti-m6A antibody immunoprecipitation with next-generation sequencing) revealed the first m6A maps in bacteria [22,23]. We used a UHPLC-QQQ-MS/MS (ultra-high pressure liquid chromatography coupled with triple-quadrupole tandem mass spectrometry) to quantified the m6A level in a wide range of bacterial species, and found high level of m6A (~0.2%) in tested Gram-negative bacteria. In both E. coli and P. aeruginosa, hundreds of m6A sites are enriched inside ORF with a consensus motif of GCCAG,
suggested the importance of bacterial m^6A modification in mRNA [24].

The Functional Roles of RNA m^6A Modification in Bacteria

In recent years, a variety of methyltransferases have been found in bacteria, which play important roles in many functional pathways. RlmF and RlmJ methylate A1618 and A2030 of 23S rRNA in Escherichia coli [25,26]. Both yhiN (rhmF) mutant and its overexpression lead to growth defect compared to the wild-type strain [25]. In addition, KsgA (the dimethyltransferase of 16S rRNA) and the resulting modifiedadenosine bases appear to be conserved in all species of eubacteria, eukaryotes, and archae [27]. KsgA is also involved in antibiotic resistance [27].

Although progress has been made on m^6A in bacterial rRNA, its occurrence in mRNA was not clear. In light of this, our recent work employed a UHPLC-QQQ-MS/MS technology to survey the m^6A modification in bacterial mRNA, and found that m^6A widely exists in a variety of bacteria [24]. A m^6A-seq has identified 265 and 109 m^6A sites in E. coli and P. aeruginosa, respectively. The functional enrichment analysis of these sites revealed that most of m^6A-modified genes are involved in pathways such as respiration metabolism, amino acids metabolism, stress response and small RNAs, which suggests important functional roles of m^6A in these genes [24]. A recent work demonstrates that several mRNA modifications (including m^6A) compromise translation and amino acid incorporation in vitro, strongly suggesting its potential similar function in vivo [28].

Challenges and Prospect Forecast

Identification of the methylases, demethylases, or binding proteins of m^6A in bacterial mRNA is key to understand the selectivity and mechanism of this modification. Unfortunately, although three m^6A methylases (RlmF, RlmJ, and KsgA) have been characterized in bacterial rRNA, they do not work on mRNA [24]. There is no close homolog of either METTL3, METTL14, FTO, or ALKBH5 in bacterial genome, suggesting that the eukaryotic m^6A machinery is largely different from the that in bacteria. Thus far the information on m^6A enzymatic machinery is absent in bacterial mRNA. Protein pulldown and genetic screen can be used to identify these proteins, given the small size of proteome and efficient genetic approaches in model bacterial species such as E. coli.

Coupling of next generation sequencing to biochemical identification of m^6A-associated proteins has led to exciting discoveries of regulatory role of m^6A modifications in eukaryotes. In prokaryotes, a crucial question is whether m^6A plays functional roles in bacterial mRNA. We envision that genetic and phenotypic characterizations of aforementioned m^6A-associated proteins would help to draw a comprehensive picture of this emerging modification in bacterial mRNA.

References


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