



A Comprehensive Review on Analytical Quality by Design (AQbD) in Product Development: A Scientific and Lifecycle Approach

Mr. Ashish Singh*

M.pharm in Pharmaceutical chemistry with honor's

Senior Executive at Sunpharma industries limited.

*Corresponding Author

Mr. Ashish Singh

M.pharm in Pharmaceutical chemistry with honor's.

Article History

Received: 07.08.2025

Accepted: 23.10.2025

Published: 15.11.2025

Abstract: Analytical Quality by Design (AQbD) is a modern scientific approach that ensures analytical methods are developed, validated, and maintained using a systematic, risk-based framework throughout the product lifecycle. AQbD emphasizes product and process understanding, design of experiments (DoE), and continuous improvement, ensuring quality is built into analytical procedures from the beginning. This review highlights the significance of AQbD in pharmaceutical product development, its regulatory foundation, and its role in enhancing the analytical lifecycle, scientific integrity, and overall product quality.

Keywords: Analytical Quality by Design, Product Lifecycle, Quality by Design, Method Validation, Risk Assessment, Continuous Improvement.

Cite this article:

Singh, A., (2025). A Comprehensive Review on Analytical Quality by Design (AQbD) in Product Development: A Scientific and Lifecycle Approach. *ISAR Journal of Science and Technology*, 3(11), 25-26.

1. Introduction

The concept of Quality by Design (QbD) has transformed pharmaceutical development by moving away from traditional end-product testing toward proactive design of quality into every stage of the process. Analytical Quality by Design (AQbD) extends this principle to analytical method development and validation, ensuring that analytical procedures are scientifically justified, risk-based, and lifecycle driven.

The International Council for Harmonisation (ICH) introduced several key guidelines—Q8 (Pharmaceutical Development), Q9 (Quality Risk Management), and Q10 (Pharmaceutical Quality System), which collectively define the framework for QbD and its application to both manufacturing and analytical sciences.

Recently, ICH Q14 (Analytical Procedure Development, 2023) was introduced to establish a harmonized, science-based framework for analytical lifecycle management. This guideline complements Q2(R2) and focuses on building comprehensive understanding of analytical procedure development, validation, and continuous performance verification. ICH Q14 emphasizes the importance of defining an Analytical Target Profile (ATP) early in the method development stage, outlining the intended purpose and performance characteristics of the analytical procedure. The ATP serves as the foundation for method optimization, validation, and lifecycle management.

The ICH Q14 framework promotes the integration of risk assessment and experimental design tools, such as Failure Mode and Effects Analysis (FMEA) and Design of Experiments (DoE), to understand how analytical parameters impact method performance.

This proactive approach ensures that analytical procedures remain robust, reliable.

Moreover, the linkage between ICH Q8, Q9, Q10, and Q14 ensures that analytical methods are developed within a broader pharmaceutical quality system, aligning analytical control strategies with process understanding. Q14 also supports regulatory flexibility by allowing method changes within an approved framework when sufficient scientific understanding is demonstrated.

Thus, AQbD under the ICH Q14 paradigm represents a knowledge-driven, risk-mitigated, and regulatory-compliant approach to analytical science. It provides a scientific basis for continuous improvement, enabling the pharmaceutical industry to achieve consistent product quality, enhanced method performance, and regulatory confidence across the entire product lifecycle.



2. Overview of Quality by Design in Pharmaceuticals

QbD in pharmaceuticals begins with defining the Quality Target Product Profile (QTPP), which describes the critical attributes required for efficacy and safety. From the QTPP, Critical Quality Attributes (CQAs) and Critical Process Parameters (CPPs) are derived. AQbD complements this by focusing on analytical methods used to monitor these CQAs, ensuring accurate and reliable measurement throughout development and commercialization.

3. Analytical Quality by Design Framework

The AQbD framework typically includes defining the Analytical Target Profile (ATP), identifying Critical Analytical Attributes (CAAs), performing risk assessment, applying Design of Experiments (DoE), developing a control strategy, and implementing lifecycle management. The ATP outlines the method performance requirements, while risk assessment (e.g., using Ishikawa or FMEA tools) identifies variables that influence analytical performance. The DoE helps establish method robustness, linearity, and accuracy.

4. Analytical Method Development and Optimization

Analytical method development involves selecting appropriate techniques such as HPLC, UV spectrophotometry, or LC-MS based on the nature of the analyte and formulation. During optimization, variables such as mobile phase composition, pH, detection wavelength, and flow rate are adjusted using statistical tools. AQbD ensures method performance is consistent and reproducible under varying conditions.

5. Analytical Method Validation and Regulatory Perspective

Analytical method validation, as described in ICH Q2(R1), verifies that the analytical procedure is suitable for its intended purpose. Validation parameters include specificity, linearity, accuracy, precision, limit of detection (LOD), limit of quantification (LOQ), and robustness. Regulatory agencies encourage AQbD principles to ensure analytical methods are fit-for-purpose and meet compliance throughout their lifecycle.

6. Analytical Lifecycle Management and Continuous Improvement

The analytical lifecycle approach, aligned with ICH Q14, emphasizes continuous method performance verification (MPV)

post-validation. Lifecycle management involves three key stages: method development, validation, and ongoing performance monitoring. Continuous improvement ensures analytical methods remain suitable even as formulations, instruments, or regulations evolve.

7. Scientific and Product Lifecycle Integration

Integration of analytical methods into the overall product lifecycle ensures that quality is monitored from research through commercial production. AQbD bridges the gap between formulation development and analytical science, supporting real-time release testing (RTRT) and process analytical technology (PAT). This approach enhances product understanding, reduces failure risk, and promotes regulatory flexibility.

8. Discussion

Implementing AQbD provides measurable benefits in efficiency, compliance, and data integrity. The approach enhances method robustness, supports knowledge management, and aligns analytical operations with global regulatory expectations. Despite its advantages, challenges remain in terms of training, resource investment, and harmonized implementation across industries.

9. Conclusion

Analytical Quality by Design (AQbD) offers a scientific framework for developing reliable and compliant analytical methods. By embedding quality principles throughout the method lifecycle, organizations can achieve consistent product performance, improved regulatory outcomes, and enhanced patient safety. AQbD is not merely a regulatory requirement and it is a pathway toward scientific excellence in pharmaceutical analysis.

References

1. ICH Q8 (R2): Pharmaceutical Development, International Council for Harmonisation, 2009.
2. ICH Q9: Quality Risk Management, ICH, 2005.
3. ICH Q10: Pharmaceutical Quality System, ICH, 2008.
4. ICH Q2 (R1): Validation of Analytical Procedures, ICH, 2005.
5. ICH Q14: Analytical Procedure Development, ICH, 2023.
6. Rathore, A.S., and Winkle, H., Quality by Design for Biopharmaceuticals, Nature Biotechnology, 27(1), 2009.
7. Sangshetti, J.N. et al., Quality by Design Approach: Regulatory Need, Arabian Journal of Chemistry, 10, 2017.
8. Furlong, L.E. et al., Analytical Lifecycle Management in Modern Pharmaceuticals, Journal of Pharmaceutical Analysis, 2022.