Research Article

Comparative Quality Assessment of Paracetamol Active Pharmaceutical Ingredient With Expired Parenteral Formulations By UV-Visible Spectrophotometry

Dr. M. V. Kumudhavalli*[1], R. Gokulakrishnan[2], P. Gokulnathan[3], S. Manoj[4], T. Arun[5], Gokul.K [6], Gokul.R [7], Gokulakrishnan.K[8]

1. Department of Pharmacognosy, Vinayaka Mission's College of Pharmacy, Vinayaka Mission's Research Foundation (Deemed to be University), Salem, Tamil Nadu, India.
2. Department of Pharmacognosy, Vinayaka Mission's College of Pharmacy, Vinayaka Mission's Research Foundation (Deemed to be University), Salem, Tamil Nadu, India.
3. Department of Pharmacognosy, Vinayaka Mission's College of Pharmacy, Vinayaka Mission's Research Foundation (Deemed to be University), Salem, Tamil Nadu, India.
4. Department of Pharmacognosy, Vinayaka Mission's College of Pharmacy, Vinayaka Mission's Research Foundation (Deemed to be University), Salem, Tamil Nadu, India.
5. Department of Pharmacognosy, Vinayaka Mission's College of Pharmacy, Vinayaka Mission's Research Foundation (Deemed to be University), Salem, Tamil Nadu, India.
6. Department of Pharmacognosy, Vinayaka Mission's College of Pharmacy, Vinayaka Mission's Research Foundation (Deemed to be University), Salem, Tamil Nadu, India.
7. Department of Pharmacognosy, Vinayaka Mission's College of Pharmacy, Vinayaka Mission's Research Foundation (Deemed to be University), Salem, Tamil Nadu, India.
8. Department of Pharmacognosy, Vinayaka Mission's College of Pharmacy, Vinayaka Mission's Research Foundation (Deemed to be University), Salem, Tamil Nadu, India.

Corresponding Author: R .Gokulakrishnan, B.Pharm,

ABSTRACT

Background: Drugs are normally withdrawn after their expiry date. There is a possibility that some drugs may still possess good potency after expiry. The present study compares paracetamol API and expired 6 months and 1 year parenteral forms using UV-Visible spectrophotometry, assisted by FTIR. **Methods**: An analytical technique based on UV-spectrophotometry has been developed and validated following ICH Q2(R1) guidelines using Shimadzu UV-1601 double beam spectrophotometer and distilled water. Scanning was done from 200-400 nm wavelength to get λmax. Calibration curve was constructed in the range 1.5-13.5 µg/mL. Linearity, absorbance, molar absorptivity, precision and purity were determined. **Results**: λmax was recorded to be 243 nm in all samples. The calibration graphs exhibited good linearity with R^2 values of 0.9999, 0.9959, and 0.9945 in standard, 6-month-expired and 1-year-expired samples, respectively, which fulfilled the criteria of $R^2 \geq 0.990$. Good precision was achieved with %RSD values ranging from 0.29% to 0.34%, which was within the 2% limit. Percentage purity ranged from 100.9% in the standard to 110.22% and 125.4% in 6-month and 1-year expired samples, respectively. Similarly, absorptivity also increased after expiration period. FTIR results indicated presence of characteristic bands of paracetamol. **Conclusion**: Good linearity, precision, and reproducibility were observed in the UV method. The expired samples possessed the characteristic molecular structure of paracetamol; however, increase in absorptivity and assay was noticed after expiration. The observations may be due to some other effects and should be analyzed using chromatographic techniques.

Keywords: Paracetamol; Expired Injection; UV–Visible Spectrophotometry; FTIR Spectroscopy; Percentage Purity; Stability; Assay; ICH Q2(R1); Parenteral Formulation.

1. Introduction

All pharmaceutical preparations have an expiry date by which time the drug maker does not give any guarantee regarding the efficacy, safety, and quality of the product. This expiry date has been obtained through actual and accelerated stability testing under certain conditions of temperature and humidity, and the rate of degradation is calculated from the results of these tests to determine the shelf life of the preparation.[1,2] After the expiry date of the preparation, even if the preparation is fine, according to the law, it should be discarded.[3] Paracetamol is an official monographed active ingredient, and the pharmacopoeia has certain general chapters giving instructions about the reference methods of analysis to judge conformity.[34,35,36] Accelerated stability testing is the usual practice based on the Arrhenius equation.[21,31]

However, there is now an emerging trend from a series of scientific papers showing that a large number of pharmaceutical products - including both solid oral formulations and parenterals - may maintain a significant amount of their initial activity for a period of months or years after their official expiry dates.[4,5] According to the findings of the United States Shelf-Life Extension Program (SLEP), which tested more than 3000 lots of over 100 drugs stored in the federal stockpile, an overwhelming majority of these lots maintained their acceptability of activity beyond their initial expiry dates, allowing for shelf life extension for a period of years. Similar reports about maintaining the activity of expired analgesics, either in tablet or injectable form, were made by recent scientific publications.[6] The mechanisms of chemical transformation leading to loss of potency of aqueous solutions of paracetamol through hydrolysis to p-aminophenol and its oxidation to quinoneimine derivatives have been described thoroughly.[5,16]

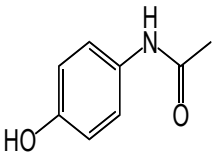
Paracetamol (acetaminophen) is one of the commonly used analgesic-antipyretics, which is present in tablet, suspension, and parenteral (IV) infusion forms for administration in situations when oral administration is not possible.[7,8,25] Since parenteral forms are usually found in emergency trolleys, operation theaters and disaster relief boxes, and are usually the first to be disposed of upon expiration, the issue of the stability of an expired paracetamol injection becomes highly relevant from both the safety aspect and the wastage of pharmaceuticals in such conditions.[9,10] In addition, unnecessary disposal of an unexpired pharmaceutical product has implications beyond the

safety and accessibility of drugs, especially since poor quality and substandard pharmaceutical products have been reported before.[22,24,32,37]

The technique of UV-visible spectrophotometry still continues to be among the most simple, economic, and easily available methods for the quantification of paracetamol, based on its unique chromophoric group and definite absorption maximum.[11,12,17,18,29,30] This study has been planned with the aims of developing and validating a UV spectrophotometric method for paracetamol and comparing it along with FTIR spectroscopy for the comparative evaluation of the quality of paracetamol API with expired parenteral formulations beyond their shelf life period by 6 months and 1 year in particular. Thus, the specific objectives of the current study have been set as follows:

2. Materials and methods

Structure



2.1. Materials

The reference/API for paracetamol and paracetamol injection formulations which were beyond their stated shelf-life period by 6 months and 1 year respectively were obtained and kept under recommended storage conditions up to the time of analysis. Distilled water was chosen as the solvent because of the solubility of paracetamol in it and favourable UV absorbance of paracetamol in it; paracetamol is highly soluble in distilled water while slightly soluble in methanol.

2.2. Instrumentation

Spectrophotometric analysis was done using a Shimadzu UV-visible double beam spectrophotometer (Model UV-1601) with matched quartz cells. The FTIR spectrum was obtained for the structural confirmation of paracetamol in aged parenteral formulation, by using ATR-FTIR technique with a spectral range of 4000-500 cm^{-1}.

2.3. Determination of λmax

The paracetamol standard was diluted using distilled water and its concentration was made 10 µg/mL, after which it was scanned from 200 nm to 400 nm. The wavelength showing maximum absorbance was noted as λmax and was taken for further estimations. This process of scanning was performed separately for the expired samples at 6 months and one year.

2.4. Preparation of standard and sample solutions

The paracetamol solution which was accurately weighted (approx 100mg) was transferred to a 100mL volumetric flask and diluted with distilled water. This gave rise to the standard solution which was subjected to serial dilution with distilled water to give working solutions with concentrations of 1.5, 3.0, 4.5, 6.0, 7.5, 9.0, 10.5, 12.0 and 13.5 µg/mL. Serial dilution with identical concentrations was performed on both the 6 months expired and the 1-year-old samples. The absorbance values were determined in triplicate at 243nm.

2.5. Calculation of absorptivity and molar absorptivity

The specific absorptivity (A11cm%) was obtained through the use of the following equation, which is normally used to relate absorbance, percentage concentration (w/v) and absorptivity a = A / bc, where A is the absorbance value, b is the length (1 cm), while c is the concentration. The molar absorptivity (εmax) was calculated from the mean absorbance value using the molar concentration of paracetamol (M.W. 151.16 g/mol).

2.6. Method validation

This method was validated according to the International Council for Harmonisation (ICH) guidelines (Q2R1) for linearity, precision (repeatability, intermediate and analyst wise precision) and assay percentage purity using the criteria listed in Table 1. Linearity was determined by plotting the correlation between absorbance and concentration in the range of 1.5-13.5 µg/ml for each of the three sample sets, using $R^2 \geq 0.990$ as the criterion for acceptability. Precision was determined by making six replicates of the 9 µg/ml standard on the same day (repeatability), on two different days (intermediate precision) and by two different analysts (analyst wise precision) with %RSD ≤ 2.0%.

Table 1. Acceptance criteria applied for method validation.

Parameter	Acceptance criterion
Linearity	$R^2 \geq 0.990$
Precision (repeatability / intermediate / analyst-wise)	%RSD ≤ 2.0%
Assay	Reported as % purity relative to label claim

2.7. Assay of standard and expired parenteral samples

The percent purity of the paracetamol in the API standard and in each parenteral drug after expiry was obtained by the use of the formula:

Percentage Purity = (Amount Determined x 100)/Weight Taken

where the Amount Determined was calculated from the ratio of the sample to the standard absorbance.

2.8. Statistical analysis

The data were presented as mean ± SD from three replicates. The percentage relative standard deviation (%RSD) was determined as (SD/mean) × 100 for all precision experiments.

3. Results

3.1. Determination of λmax

The spectrum of the paracetamol reference solution, analyzed in the range 200-400 nm, showed maximum absorption at 243 nm. The two parenteral solutions expired after six months and one year also showed the same maximum at 243 nm, implying that the chromophore of paracetamol was unchanged even after expiration.

3.2. Calibration data and linearity

The calibration curves were found to be linear in the range of concentrations from 1.5-13.5 µg/mL for both the standards as well as for the expired parenteral sample (Table 2). The average absorbance values of the standard was found to vary between 0.124 and 0.951, while those of the 6 month expired sample was found to vary between 0.144 and 0.983.

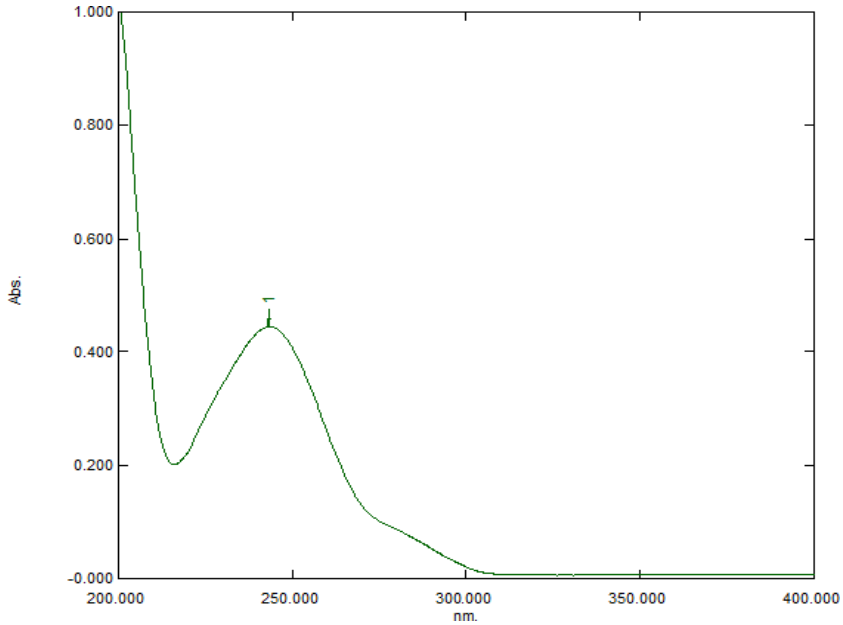


Table 2. Mean absorbance of paracetamol at 243 nm across the calibration range (1.5-13.5 µg/mL) for the standard, 6-month-expired and 1-year-expired parenteral samples (n = 3 per concentration).

Concentration (µg/mL)	Mean absorbance (Standard)	Mean absorbance (6-month expired)	Mean absorbance (1-year expired)
1.5	0.124	0.144	0.245
3.0	0.235	0.263	0.334
4.5	0.336	0.327	0.413
6.0	0.439	0.485	0.552
7.5	0.535	0.568	0.679
9.0	0.641	0.648	0.789
10.5	0.740	0.745	0.843
12.0	0.849	0.856	0.951
13.5	0.951	0.983	1.053

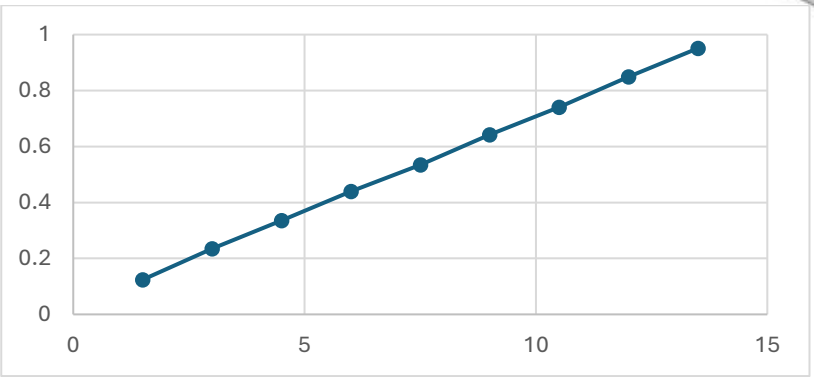


Figure No. 1: Standard Absorbance Curve of Paracetamol UV- Method

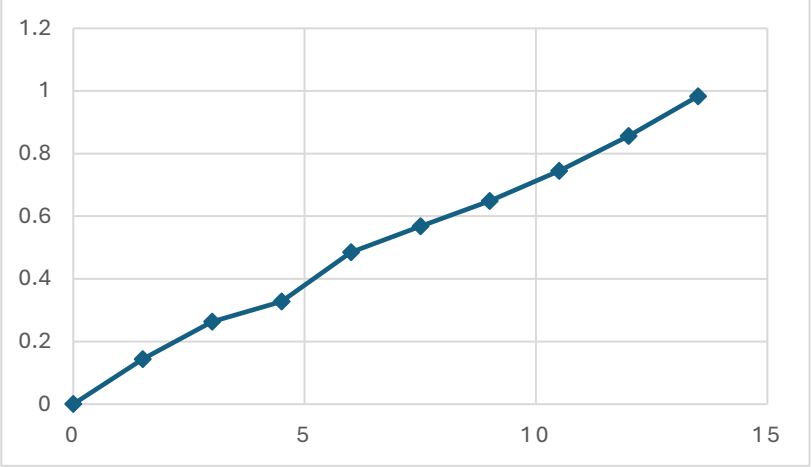


Figure No. 2: Standard Absorbance Curve of Paracetamol (6 MONTH)

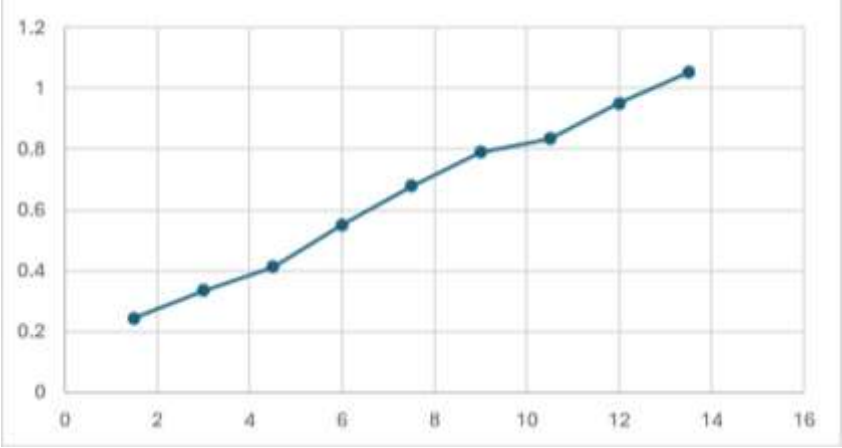


Figure No. 3: Standard Absorbance Curve of Paracetamol (1 YEAR)

Table 3. Linear regression parameters for the calibration curves of paracetamol standard, 6-month-expired and 1-year-expired parenteral samples.

Parameter	Standard	6-month expired	1-year expired
n (calibration points)	9	9	9
Concentration range (µg/mL)	1.5-13.5	1.5-13.5	1.5-13.5
Slope (b)	0.0684	0.0682	0.0687
Intercept (a)	0.0256	0.0465	0.1360
Correlation coefficient (R)	0.9999	0.9979	0.9972
R^2	0.9999 (99.99%)	0.9959 (99.59%)	0.9945 (99.45%)
Acceptance criterion	$R^2 \geq 0.990$	$R^2 \geq 0.990$	$R^2 \geq 0.990$

It can be seen from Table 3 that all the three equations of regression analysis passed the defined acceptance criterion of $R^2 > 0.990$, proving the linearity of the process even in the case of expired samples.

3.3. Absorptivity and molar absorptivity

The mean specific absorptivity (A11cm%) of paracetamol was 736.68 for the standard, 776.9 for the 6-month-expired parenteral and 971.18 for the 1-year-expired parenteral (Table 4). The corresponding mean molar absorptivity (εmax) values were 111,374,666, 117,543,975 and 146,838,163 respectively, following the same increasing trend with the duration of storage beyond expiry.

Table 4. Mean specific absorptivity and molar absorptivity of paracetamol in the standard and expired parenteral samples.

Sample	Mean $A^{1}_{1}{}^{cm}$% (absorptivity)	Mean εmax (molar absorptivity)
Standard (API)	736.68	111,374,666
6-month-expired parenteral	776.90	117,543,975
1-year-expired parenteral	971.18	146,838,163

3.4. Precision

Precisions were determined using 9 µg/mL standard solution. The repeatability was carried out six times in one day to give a mean absorbance of 0.6405 with SD 0.0019 and %RSD 0.29%. Inter-day precisions carried out thrice in two different days to give a mean absorbance of 0.6402 with SD 0.0021 and %RSD 0.32%, while the intra-analyst precision carried out three times each by two different analysts to give a mean absorbance of 0.6407 with SD 0.0022 and %RSD 0.34% (Table 5).

Table 5. Precision of the UV-spectrophotometric method for paracetamol (9 µg/mL standard, n = 6).

Precision study	Mean absorbance	SD	%RSD
Repeatability (intra-day)	0.6405	0.0019	0.29%
Intermediate precision (inter-day)	0.6402	0.0021	0.32%
Analyst-wise precision	0.6407	0.0022	0.34%

3.5. Assay of standard and expired parenteral samples

Paracetamol purity percentage, based on label claim, was found to be 100.9% for the API standard, 110.22% for the 6 month-expired parenteral sample, and 125.4% for the 1 year-expired parenteral sample (Table 6). It may be observed that instead of a drop in the amount, the measured amount of both the expired samples was greater than that of the standard.

Table 6. Assay (percentage purity) of paracetamol standard and expired parenteral formulations.

Sample	Percentage purity (% of label claim)
Standard (API)	100.9%
6-month-expired parenteral	110.22%
1-year-expired parenteral	125.4%

3.6. FTIR analysis

The FTIR spectrum of the aged paracetamol sample showed retained characteristic absorption bands at 3375 cm^{-1} (N-H/O-H stretch), 2917 and 2879 cm^{-1} (C-H stretch), 1648 cm^{-1} (C=O stretch, amide I), 1557 cm^{-1} (N-H bend/C-N stretch, amide II), 1513 cm^{-1} (aromatic C=C stretch), and a doublet at 835 and 796 cm^{-1} corresponding to the out-of-plane C-H bending of a para-disubstituted benzene ring (Table 7). These bands are all consistent with the molecular structure of paracetamol (4-hydroxyacetanilide) and confirmed that the core chemical structure had not degraded.

Table 7. FTIR spectral assignments for paracetamol.

Wavenumber (cm^{-1})	Functional group / vibration
3375	N-H stretch (amide) / O-H stretch (phenol)
2917, 2879	C-H stretch (aromatic and methyl)
1648	C=O stretch (amide I)
1557	N-H bend / C-N stretch (amide II)
1513	Aromatic C=C ring stretch
1453	CH_3 bending
1374, 1326, 1246	C-N stretch, O-H bend, C-O stretch (phenolic)
1081, 1042	C-O stretch (phenol)
990, 932, 884	Aromatic C-H bending
835, 796	Para-disubstituted benzene ring (out-of-plane C-H bend)

588	Ring skeletal deformation

4. Discussion

The present study evaluated paracetamol API and parenteral preparations stored for 6 months and 1 year beyond expiry using UV-visible spectrophotometry supported by FTIR analysis. The λmax remained constant at 243 nm in all samples, indicating retention of the characteristic UV-absorbing chromophore of paracetamol.

The calibration curves showed satisfactory linearity over 1.5–13.5 µg/mL, with R^2 values of 0.9999, 0.9959, and 0.9945 for the standard, 6-month-expired, and 1-year-expired samples, respectively. Precision results showed %RSD values below 0.5%, indicating good analytical precision and compliance with the predefined acceptance limit of 2%.

The apparent assay values increased from 100.9% in the standard to 110.22% and 125.4% in the 6-month- and 1-year-expired samples, respectively. This increase should not be interpreted as an actual increase in paracetamol content, as single-wavelength UV analysis may be influenced by degradation products, matrix effects, baseline variation, or other UV-absorbing substances. Therefore, the apparent increase requires confirmation using a stability-indicating method such as HPLC.

FTIR spectra retained the characteristic functional-group peaks of paracetamol, supporting its structural identity in the tested samples. Overall, the results provide preliminary evidence of retained spectral and structural characteristics up to 1 year after expiry; however, further specific stability studies are required before definitive conclusions regarding potency and quality can be made.

5. Conclusion

The developed UV-spectrophotometric procedure for the estimation of paracetamol at 243 nm proved to be linear ($R^2 \geq 0.990$), precise (%RSD < 0.5%) and reproducible for both the API standard and the parenteral formulations, six months and one year after their expiry date. FTIR spectrum analysis established the preservation of the structural identity of paracetamol in the expired parenteral formulations. The % purity of both expired batches exceeded 100% of the label claim, along with the unchanged spectral pattern, which implies no substantial chemical deterioration of the drug over the given period of time, even though the increase of the absorptivity and assay during storage needs to be proven with stability-indicating chromatographic techniques. These findings contribute to the existing literature data showing that the actual shelf life of a pharmaceutical preparation is not always accurately predicted by the product expiry date, and further research (HPLC-based stability-indicating assay of expired parenteral preparations) will help establish more logical approaches to extending shelf life of pharmaceuticals and reducing drug waste.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgements

The authors thank the Department of Pharmaceutical Analysis, Vinayaka Mission's College of Pharmacy, Salem, for providing the laboratory facilities used in this study.

References

1. World Health Organization. Quality assurance of pharmaceuticals. Geneva: World Health Organization; 2007. Thirty-sixth report.
2. U.S. Food and Drug Administration. Code of Federal Regulations, Title 21 [Internet]. Silver Spring (MD): U.S. Food and Drug Administration; 2018 [cited 2026 Sep 23]. Available from: https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm
3. U.S. Food and Drug Administration. Expiration dates: questions and answers [Internet]. Silver Spring (MD): U.S. Food and Drug Administration [cited 2026 Sep 23]. Available from: https://www.fda.gov/drugs/pharmaceutical-quality-resources/expiration-dates-questions-and-answers
4. Lyon RC, Taylor JS, Porter DA, Prasanna HR, Hussain AS. Stability profiles of drug products extended beyond labeled expiration dates. J Pharm Sci. 2006;95(7):1549-60. doi:10.1002/jps.20636.
5. Cantrell L, Suchard JR, Wu A, Gerona RR. Stability of active ingredients in long-expired prescription medications. Arch Intern Med. 2012;172(21):1685-7. doi:10.1001/archinternmed.2012.4501.
6. Sharma S, Sharma AK, Moe HW, Khanapure A, Mohan P. A study to investigate the chemical potency, physical stability, and efficacy of analgesic agents over a period of two years post their expiry date. Med J Armed Forces India. 2022;78:S194-S200.
7. Graham GG, Davies MJ, Day RO, Mohamudally A, Scott KF. The modern pharmacology of paracetamol: therapeutic actions, mechanism of action, metabolism, toxicity and recent pharmacological findings. Inflammopharmacology. 2013;21(3):201-32. doi:10.1007/s10787-013-0172-x.
8. Duggan ST, Scott LJ. Intravenous paracetamol (acetaminophen). Drugs. 2009;69(1):101-13. doi:10.2165/00003495-200969010-00007.

9. Acosta A, Vanegas EP, Rovira J, Godman B, Bochenek T. Medicine shortages: gaps between countries and global perspectives. Front Pharmacol. 2019;10:763. doi:10.3389/fphar.2019.00763.
10. Mani A, Thawani V. The persisting environmental problem of disposal of expired and unused medicines. J Mahatma Gandhi Inst Med Sci. 2019;24(1):13-16. doi:10.4103/jmgims.jmgims_43_18.
11. Ali O, Jain H, Parihar NB, Agarwal P. UV-spectrophotometric assay of paracetamol in 1% w/v pharmaceutical infusion samples of different marketed brands: a simple and reliable analytical method. Int J Res Pharm Pharm Sci. 2026;11(2):14-17.
12. Nihala P, Noushim CK, Nandana M, Prakash PA, Yasmin KNM, Saimah MP. Recent advances in UV-visible spectrophotometric method development and validation for pharmaceutical drug analysis. Int J Med Sci. 2026;6(1):1-16.
13. International Council for Harmonisation. Q2(R1): validation of analytical procedures: text and methodology. Geneva: International Council for Harmonisation; 2005.
14. Bunaciu AA, Fleschin S, Hoang VD, Aboul-Enein HY. Advanced analytical approach based on combination of FT-IR and chemometrics for quality control of pharmaceutical preparations. Pharmaceutics. 2022.
15. Koshy KT, Lach JL. Stability of aqueous solutions of N-acetyl-p-aminophenol. J Pharm Sci. 1961;50(2):113-8. doi:10.1002/jps.2600500204.
16. Fairbrother JE. Acetaminophen. In: Florey K, editor. Analytical profiles of drug substances. Vol. 3. New York: Academic Press; 1974. p. 1-109.
17. Ben-Hander GM, Gaeth ME, Otmaan NA. Method validation for determination of paracetamol in tablet dosage form using UV-visible spectrophotometer. Sirte Univ J Med Sci. 2022;1(2):16-21. doi:10.37375/sjms.v1i2.327.
18. Elsaman T. Development and validation of the UV spectrophotometric method for simultaneous determination of paracetamol and pseudoephedrine in bulk and combined tablet dosage form. Pharm Chem J. 2021. doi:10.1007/s11094-021-02360-w.
19. Zapata F, López-Fernández A, Ortega-Ojeda F, Quintanilla G, García-Ruiz C, Montalvo G. Introducing ATR-FTIR spectroscopy through analysis of acetaminophen drugs: practical lessons for interdisciplinary and progressive learning for undergraduate students. J Chem Educ. 2021;98(8):2675-86. doi:10.1021/acs.jchemed.0c01231.
20. Mallah MA, Sherazi STH, Bhanger MI, Mahesar SA, Bajeer MA. A rapid Fourier-transform infrared (FTIR) spectroscopic method for direct quantification of paracetamol content in solid pharmaceutical formulations. Spectrochim Acta A Mol Biomol Spectrosc. 2015;141:64-70. doi:10.1016/j.saa.2015.01.036.
21. International Council for Harmonisation. Q1A(R2): stability testing of new drug substances and products. Geneva: International Council for Harmonisation; 2003.
22. Alnahas F, Yeboah P, Fliedel L, Abdin AY, Alhareth K. Expired medication: societal, regulatory and ethical aspects of a wasted opportunity. Int J Environ Res Public Health. 2020;17(3):787. doi:10.3390/ijerph17030787.
23. Chidiac AS, Buckley NA, Noghrehchi F, Cairns R. Paracetamol (acetaminophen) overdose and hepatotoxicity: mechanism, treatment, prevention measures, and estimates of burden of disease. Expert Opin Drug Metab Toxicol. 2023;19(5):297-317. doi:10.1080/17425255.2023.2223959.
24. World Health Organization. WHO global surveillance and monitoring system for substandard and falsified medical products. Geneva: World Health Organization; 2017.
25. Macario A, Royal MA. A literature review of randomized clinical trials of intravenous acetaminophen (paracetamol) for acute postoperative pain. Pain Pract. 2011;11(3):290-6. doi:10.1111/j.1533-2500.2010.00426.x.
26. Shah DA, Patel NJ, Baldania SL, Chhalotiya UK, Bhatt KK. Stability indicating LC-method for estimation of paracetamol and lornoxicam in combined dosage form. Sci Pharm. 2011;79(1):113-22. doi:10.3797/scipharm.1012-03.
27. Jahan MS, Islam MJ, Begum R, Kayesh R, Rahman A. A study of method development, validation, and forced degradation for simultaneous quantification of paracetamol and ibuprofen in pharmaceutical dosage form by RP-HPLC method. Anal Chem Insights. 2014;9:75-81. doi:10.4137/ACI.S18651.
28. Karunakaran K, Navaneethan G, Elango KP. Development and validation of a stability-indicating RP-HPLC method for simultaneous determination of paracetamol, tramadol HCl and domperidone in a combined dosage form. Trop J Pharm Res. 2012;11(1):99-106.
29. Qasim FO, Ameen AJM, Qadirc KM, Hamid MA, Yousif NI. A simple stability-indicating UV spectrophotometric method developed and validated for detection of paracetamol in liquid and solid dosage forms and biological fluid: application and comparison. Pak J Life Soc Sci. 2024;22(2):2838-50. doi:10.57239/PJLSS-2024-22.2.00208.
30. Sharma S, Pareek A, Joshi R, Bhardwaj YR, Jain V, Jadon G. Development and validation of a UV spectroscopic method for analysis of paracetamol in bulk powder and tablet. Orient J Chem. 2013;29(2):787-92. doi:10.13005/ojc/290261.
31. Sakti B, Ammar AH, Salsabila M, Putra FP, Ragil BS, Mulyaningsih M, et al. A review: accelerated stability testing and shelf-life prediction of pharmaceutical products using the Arrhenius equation. Devotion J Res Community Serv. 2026;7(6). doi:10.59188/devotion.v7i6.25720.

32. Organisation for Economic Co-operation and Development. Management of pharmaceutical household waste: limiting environmental impacts of unused or expired medicine. Paris: OECD Publishing; 2022.
33. Ali JG, Muhammad I, Hamid S, Ali AM, Shoaib H, Tasleem S. Simultaneous determination and quantification of paracetamol, caffeine and orphenadrine citrate using stability indicating HPLC method in a fixed-dose combination tablet dosage form. Ann Pharmacol Pharm. 2020;5(3):1185.
34. British Pharmacopoeia Commission. British Pharmacopoeia: paracetamol monograph. London: The Stationery Office; 2023.
35. Indian Pharmacopoeia Commission. Indian Pharmacopoeia: paracetamol monograph. Ghaziabad: Indian Pharmacopoeia Commission; 2022.
36. United States Pharmacopeial Convention. USP general chapter <857>: ultraviolet-visible spectroscopy. Rockville (MD): United States Pharmacopeial Convention; 2023.
37. World Health Organization. WHO Expert Committee on Specifications for Pharmaceutical Preparations: fifty-sixth report. WHO Technical Report Series No. 1044. Geneva: World Health Organization; 2023.