



HAL
open science

Simultaneous quantification of four hormone therapy drugs by LC-MS/MS: Clinical applications in breast cancer patients

Bochra Mansour, Clarice Ngo, Dimitri Schlemmer, Pascal Robidou, Juliette Blondel, Clémence Marin, Gaëlle Noé, Adrien Procureur, Mathieu Jamelot, Joseph Gligorov, et al.

► To cite this version:

Bochra Mansour, Clarice Ngo, Dimitri Schlemmer, Pascal Robidou, Juliette Blondel, et al.. Simultaneous quantification of four hormone therapy drugs by LC-MS/MS: Clinical applications in breast cancer patients. *Journal of Pharmaceutical and Biomedical Analysis*, 2024, 242, pp.116032. 10.1016/j.jpba.2024.116032 . hal-04582761

HAL Id: hal-04582761

<https://hal.science/hal-04582761>

Submitted on 22 May 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

1 **Simultaneous quantification of four hormone therapy**
2 **drugs by LC-MS/MS: clinical applications in breast cancer**
3 **patients**

4 Bochra Mansour^{1†}, Clarice Ngo^{2†}, Dimitri Schlemmer¹, Pascal Robidou², Juliette Blondel²,
5 Clémence Marin², Gaëlle Noé², Adrien Procureur², Mathieu Jamelot³, Joseph Gligorov³, Joe-
6 Elie Salem², Noël Zahr^{1,2*}

7 *1.AP-HP. Sorbonne Université, Laboratoire de suivi thérapeutique pharmacologique spécialisé, F-*
8 *75013 Paris, France*

9 *2.AP-HP Sorbonne Université, Pitié-Salpêtrière Hospital, Department of Pharmacology, CIC-1901,*
10 *Pharmacokinetics and Therapeutic Drug Monitoring Unit, UMR-S 1166, F-75013 Paris, France*

11 *3. Department of Medical Oncology, Institut Universitaire de Cancérologie, Sorbonne University, AP-*
12 *HP, Tenon Hospital, Paris, France*

13

14 † Contributed equally

15 * Corresponding author : Service de Pharmacologie, Hôpital Pitié-Salpêtrière (AP-HP), 75013 Paris, France
16 *E-mail address: noel.zahr@aphp.fr (N. Zahr).*

17 **Abstract**

18 **Introduction**

19 Aromatase inhibitors such as anastrozole, letrozole, exemestane and selective estrogen down-
20 regulator (SERD) fulvestrant are used mostly to treat breast cancer estrogen receptor positive
21 in post-menopausal women. These drugs are given either through the oral route or by
22 intramuscular injection. They have shown great inter-individual variability with a risk of
23 cardiometabolic disorders. Hence the importance of their therapeutic drug monitoring not
24 only for exposure-efficacy but also exposure-toxicity. We describe here a LC-MS/MS method
25 for the simultaneous quantification of anastrozole, letrozole, exemestane and fulvestrant in
26 human plasma.

27 **Material and methods**

28 Plasma samples were prepared by a single-step protein precipitation. The liquid
29 chromatography system was paired with a triple quadrupole mass spectrometer.
30 Quantification were achieved in Multiple Reactions Monitoring mode and the electrospray
31 ionization was in positive mode.

32 **Results**

33 The method demonstrated consistent analytical performance across various parameters,
34 including linearity, specificity, sensitivity, matrix effect, upper and lower limits of
35 quantification, extraction recovery, precision, accuracy, hemolysis effect, dilution integrity,
36 and stability under different storage conditions, in accordance with established guidelines.

37 The analysis time for each run was 4 minutes. Calibration curves exhibited linearity within the
38 1-100 ng/ml range, with correlation coefficients > 0.99 for the four analytes. Plasma
39 concentrations from 42 patients were integrated into the selected calibration.

40 Stability assessments indicated that the four drugs remained stable at -20°C for three months,
41 15 days under refrigeration, up to 7 days at room temperature, and after three freeze-thaw
42 cycles

43 **Conclusion**

44 We have developed and validated this quantitative method for therapeutic drug monitoring of
45 those four hormone therapy drugs: anastrozole, letrozole, fulvestrant and exemestane. This
46 method can be also used for future clinical pharmacokinetics /pharmacodynamics studies.

47 **Keywords:** anastrozole, exemestane, letrozole, fulvestrant, mass spectrometry, Therapeutic
48 drug monitoring (TDM)

49 **1 Introduction**

50 Breast cancer is the most prevalent cancer among women in Europe and is the leading
51 cause of cancer-related death. The worldwide incidence of breast cancer is estimated to be 2.3
52 million cases [1]. Approximately 80% of breast cancers are estrogen receptor (ER)–positive:
53 in such cases, cancer cells proliferate in response to estrogen. Hormone therapy with drugs
54 such as aromatase inhibitors (AIs) and selective ER downregulators (SERDs) is indicated in
55 the treatment of this type of cancer in mostly postmenopausal women and to a lesser extent,
56 premenopausal women when combined with a central blocking. These agents can either
57 inhibit synthesis of estrogen or cause the degradation of its receptor [2].

58 AIs compete with aromatase, preventing it from converting androgen into estrogen.
59 Commonly prescribed AIs are anastrozole (ANA), letrozole (LET), and exemestane (EXE)
60 [3]. Analogous in structure to the natural substrate of aromatase, EXE is a steroidal compound
61 that inactivates the enzyme by irreversibly binding to it, whereas ANA and LET bind
62 reversibly to aromatase. Fulvestrant (FUL), a steroidal SERD, is a high-affinity ER
63 antagonist. When FUL binds to ERs, it induces their degradation [4]. Accordingly, estrogen
64 levels could serve as biomarkers of treatment efficacy. However, estrogen concentrations
65 found in patients taking LET or EXE [5] can be subpicomolar, and the quantitative
66 determination of estrogen in plasma relies on an expensive albeit very sensitive mass
67 spectrometry method [6].

68 AIs and FUL are administered differently: AIs are taken orally on a daily basis, while
69 FUL is given intramuscularly once a month. The half-lives of AIs—ANA (48–96 h), LET
70 (48 h), EXE (24 h)—and FUL (50 d) also differ greatly[7]. These drugs are administered at
71 fixed doses despite great interpatient variability in concentrations of AIs and FUL: for
72 example, patients' plasma LET concentrations can vary from 17.0 to 301.3 ng/mL [8].

73 As adjuvant therapy with AIs can last over 5 years, exposure-toxicity evaluation is of
74 value for therapeutic drug monitoring purposes. The literature offers no definitive exposure-
75 efficacy studies [3, 9]. However, the review by Nabholz et al. [10] proposed target
76 concentrations for ANA ($C_{\min} \geq 34.2$ ng/mL), EXE ($C_{\max} = 4.1$ ng/mL), and LET ($C_{\min} \geq 85.6$
77 ng/mL). The same results was found with a promising TDM recommendation for LET and
78 exploratory TDM recommendation for ANA and EXE [5]. ANA has a linear relationship
79 between dose and exposure across doses ranging from 0.5 to 10 mg [11]. Considering the
80 available data, it may be prudent to contemplate dose escalation of ANA for patients with a
81 C_{\min} below 34.2 ng/mL [12]. EXE undergoes extensive metabolism, with 17-hydroxy-
82 exemestane being the sole active metabolite but with a concentration ten times lower than
83 exemestane concentration and with a less anti-estrogenic effect [5]. Exemestane has not
84 demonstrated a clear relationship between exposure and toxicity. Generally, it is well-
85 tolerated, as evidenced by phase I studies where single doses of up to 800 mg and multiple
86 doses of up to 200 mg were administered, and it has a linear dose-exposure relationship [13].
87 In the absence of a defined exposure–efficacy target, the median C_{\max} of 7.7 ng/mL could
88 serve as a reference for therapeutic drug monitoring (TDM), correlating with a calculated
89 trough concentration of 4.1 ng/mL [5]. LET has shown a linear dose-exposure relationship
90 up to the standard dose of 2.5mg once a day while at higher doses the exposure is non-
91 linear. Until then, the target for LET TDM is $C_{\min} \geq 85.6$ ng/ml [5]. A pharmacokinetics study
92 of FUL has proved that C_{\max} and $AUC_{(0-28)}$ demonstrate a dose-dependent increase and that
93 the exposure was proportional to the dose [14].

94 Monitoring of these hormone therapy drugs could offer a better understanding of
95 pharmacokinetic profiles, such as exposure-response and exposure-toxicity; permit evaluation
96 of patient compliance; and provide clinicians a tool for personalized breast cancer treatments.
97 The method presented here aims to simultaneously quantify these commonly prescribed

98 agents after simple pretreatment of plasma samples and has the advantage of rapid run time
99 for routine laboratory application.

100 **2 Materials and methods**

101 **2.1 Chemicals and reagents**

102 ANA, LET, EXE, FUL, anastrozole-13C4, fulvestrant-D5, and letrozole-13C2,15N2
103 were purchased from AlsaChim (Illkirch, France), their purity was higher than 98%.
104 exemestane-13C,D3, from Toronto Research Chemicals (Toronto, Canada), its purity was
105 higher than 95%; and methanol, acetonitrile, and DMSO, from Carlo Erba Reagents (Val-de-
106 Reuil, France), Merck KGaA (Darmstadt, Germany), and PanReac AppliChem (Schiltigheim,
107 France), respectively. Water used was purified with an ELGA PURELAB system.

108 Drug-free, blank plasma was supplied by the Établissement Français du Sang (French
109 Blood Establishment) in Paris, France. All reagents used were of the highest available
110 analytical grades.

111 **2.2 Preparation of stock solutions, standards, and quality control samples**

112 Stock solutions were prepared in different solvents: ANA was dissolved in
113 acetonitrile; EXE in DMSO; and LET and FUL in methanol. Individual stock solutions of
114 each analyte had concentrations of 1 mg/mL. Quality control samples (QCs) and calibration
115 standards were obtained by dilution of these stock solutions in methanol:water (50:50, v/v).
116 QCs were prepared in blank plasma at concentrations of 5, 45 and 90 ng/mL (QC1, QC2 and
117 QC3, respectively). This quantitative method covers a range of 1 to 100 ng/mL (1, 10, 25, 50,
118 75, 100 ng/mL) for the four compounds.

119 For samples with a concentration above the linear range, a fourth QC was added
120 (QC4) at concentrations of 150 ng/mL for ANA, 200 ng/mL for EXE, 400 ng/mL for FUL,
121 and 1,000 ng/mL for LET, corresponding to the upper limits of quantification (ULOQs)
122 identified.

123 Internal standard (IS) stock solutions were prepared at a concentration of 1 mg/mL. A
124 mixture of anastrozole-13C4, exemestane-13C,D3, letrozole-13C2,15N2, and fulvestrant-2H5
125 was diluted in methanol:acetonitrile (50:50, v/v) to obtain a 75 ng/mL solution.

126 **2.3 Analytical conditions**

127 An Acquity UPLC BEH C18 column (2.1 × 50 mm, 1.7- μ m particle size) (WATERS,
128 Milford, Massachusetts, US) was used for chromatographic separation. The Nexera® LC40
129 LC system (Shimadzu Corporation, Kyoto, Japan) was paired with a triple quadrupole mass
130 spectrometer (LCMS-8060NX, Shimadzu Corporation, Kyoto, Japan) equipped with a 20 μ L
131 injection loop. The mobile phase was composed of 0.1% formic acid and acetonitrile and had
132 a flow rate of 0.4 mL/min. The analysis run time was 4 min. Quantification were achieved in
133 Multiple Reaction Monitoring (MRM) mode, and electrospray ionization (ESI) was in
134 positive mode. Transitions (m/z)—294.20 > 225.20 for ANA, 286.10 > 190.10 for LET,
135 297.20 > 121.10 for EXE, and 607.30 > 589.40 for FUL—were monitored. Data acquisition
136 and quantification were performed using Labsolution V5.99 SP2 (Shimadzu Corporation,
137 Kyoto, Japan) and Insight V3.7 SP3 (Shimadzu Corporation, Kyoto, Japan), respectively.

138 **2.4 Sample pretreatment**

139 Plasma samples were prepared by one-step protein precipitation: 150 μ L of IS solution
140 was added to 50 μ L of patient plasma, a calibrator sample, or a QC. The tube was agitated for
141 5 min at 2,000 rpm and centrifuged for another 5 min at 13,000 rpm. Next, 100 μ L of

142 supernatant was diluted in 100 μ L of water and a volume of 10 μ L was injected into the LC-
143 MS/MS system.

144 **2.5 Method validation**

145 Validation was conducted in accordance with guidelines of the European Medicines
146 Agency (EMA) and industry guidance from the US Food and Drug Administration (FDA) for
147 bioanalytical method validation [15-17]. The parameters verified were selectivity, specificity,
148 matrix effect, linearity, accuracy and precision, lower limit of quantification (LLOQ) and
149 upper limits of quantification (ULOQ), carryover, stability, extraction recovery, and dilution
150 integrity. Hemolysis effect, as described by D’Cunha et al. [18], was also tested.

151 **2.5.1 Lower and upper limits of quantification**

152 For each analyte, the LLOQ was matched to the lowest plasma concentration
153 quantifiable with reliable accuracy and precision, corresponding to a coefficient of variation
154 (CV) and bias under 20%; and the ULOQ, to the highest quantifiable plasma concentration,
155 with a CV and bias under 15%.

156 **2.5.2 Selectivity and specificity**

157 We tested for drugs potentially associated with these compounds that could interfere
158 with analyte quantification. Patient plasma samples containing these drugs, but none of the
159 analytes, were selected. Thus, plasmas from 6 different patients treated with everolimus,
160 sirolimus, posaconazole, voriconazole, aciclovir, ganciclovir, or ribociclib were used. Spiked
161 plasma samples were used for tamoxifen and palbociclib. No interference was detected when
162 the peak area for the plasma containing a cotreatment was <20% of the peak area for the first
163 calibration standard at the retention time of the analyte. The selectivity and specificity of the
164 IS was tested through the same procedure but with a limit of 5%.

165 **2.5.3 Stability**

166 The stability of the four molecules was measured under different conditions: after
167 short-term storage for 7 days at room temperature, short-term storage for 15 days when
168 refrigerated at 4 °C, long-term storage for a total period of 3 months at -20 °C, 3 freeze-thaw
169 cycles (from -20 °C to room temperature), and leaving in autosampler at 15 °C for 9 days.

170 Stability was assessed by comparing accuracy and precision of QCs at two
171 concentration levels (QC1 and QC3) before and after exposure to the aforementioned
172 conditions. Analytes were considered stable when measured concentrations were within ±15%
173 of the baseline QC3 concentration and ±20% of the baseline QC1 concentration. All QC
174 levels were measured in triplicate. These tests sought to reproduce all possible storage
175 conditions to which patient samples could be exposed during routine laboratory operations.

176 **2.5.4 Dilution integrity**

177 Dilution integrity was tested to determine whether quantification of a sample, diluted
178 with blank plasma, whose initial concentration was above the validated calibration range is
179 precise and accurate. Spiked samples with a concentration above the ULOQ were diluted (1:5
180 or 1:2) with blank plasma to levels falling within the calibration range. Precision and accuracy
181 were considered satisfactory when the measured concentration of the diluted sample did not
182 deviate from the nominal concentration by >15%.

183 **2.5.5 Linearity**

184 A weighting factor of 1/X was applied to the linear calibration curve. The calibration
185 curve was plotted with 6 calibration points (G1 to G6) by determining the ratio of the analyte
186 peak area to the IS peak area ($r^2 > 0.99$). The validation criteria were: ($r^2 > 0.99$), both bias
187 and CV of the nominal concentration had to be < 15% for all standards (G2 to G6) and

188 <20% for the G1. The calibration curve follows a linear regression with a 1/x weighting
189 factor.

190 **2.5.6 Matrix effect, hemolysis effect, and extraction recovery**

191 The matrix effect was evaluated for two QC concentration levels (QC1 and QC3).
192 Freshly prepared QCs and spiked blank plasma were prepared on the same day. Selected
193 plasma samples were drawn from patients taking everolimus, sirolimus, posaconazole,
194 voriconazole, aciclovir, ganciclovir, itraconazole, or ribociclib. The CV of the IS-normalized
195 matrix factor should be <15%, and the peak area of the spiked plasma should not deviate by
196 more than 15% of the peak area for QC1 and QC3 levels.

197 In the preanalytical phase, hemolysis could be a source of interference. Hemolysis
198 effect was tested according to the method described by D’Cunha et al. [18]. The
199 concentrations of freshly prepared QC1 and QC3 ($n = 6$) were compared with that of 2%-
200 hemolysis spiked blank plasma extracted in sextuplicate ($n = 12$).

201 Extraction recovery was evaluated for three QC concentration levels (QC1, QC2, and
202 QC3). No acceptance criteria were established, but CV should be homogenous for all levels
203 and ideally should not deviate by >20%.

204 **2.5.7 Carryover**

205 This parameter was evaluated after an autopurge and tested at the highest (G6) and
206 lowest (G1) calibration levels. A sequence of three G6 samples followed by three G1 samples
207 was repeated four times. A G1 sample was injected before this sequence, and its peak area
208 was used as the reference peak area for the analyte and the IS area. Carryover is not observed
209 if G1 peak areas are <20% of the reference peak area and <5% of the reference IS area.

210 **2.5.8 Precision and accuracy**

211 Intra-day precision and accuracy were measured in sextuplicate ($n = 6$ for samples at
212 each QC concentration and G1). Inter-day precision and accuracy were evaluated by
213 measuring sample at each QC concentration and G1 ($n = 18$) in triplicate over 6 days. CV (%)
214 and bias (%) should be within 20% for G1 and QC1, and 15% for QC2, QC3, and QC4.

215 **2.6 Clinical applications**

216 This validated LC-MS/MS plasma quantification method was applied to a cohort of
217 15 female breast cancer patients, with a mean age of 63 years. A total of 42 samples of plasma
218 were analyzed, from patients treated with LET ($n = 37$), EXE ($n = 5$), and FUL ($n = 4$). The
219 samples of plasma were collected at different time points in the treatment cycle: before
220 treatment initiation, before achieving a steady state, at steady state, or after the end of
221 treatment. All LET-treated patients received concurrent ribociclib therapy at a dose of 600
222 mg, administered once daily 3 weak/month. One patient, who was also undergoing FUL
223 treatment (administered monthly at a dosage of 500 mg), was additionally treated with EXE at
224 25mg and ribociclib at 600mg.

225 **3 Results**

226 **3.1 Optimization of LC-MS/MS conditions**

227 Parameters chosen for each analyte are described in **Table 1**. Phase A was 0.1%
228 formic acid; phase B, acetonitrile. The chromatograms of LLOQ, blank plasma, and patient
229 plasma peaks are presented in **Figure 1**.

230 **3.2 Method validation**

231 **3.2.1 Precision and accuracy**

232 For all QC concentrations and G1, intra-day and inter-day precision and accuracy met
233 the defined criteria (within 20% for G1 and QC1, and within 15% for QC2, QC3, and QC4)
234 (Table 2).

235 **3.2.2 Stability**

236 The four analytes were stable after short-term storage at room temperature for 7 days,
237 refrigeration at 4 °C for 15 days, and storage at -20 °C for 3 months. All analytes were stable
238 after 3 freeze-thaw cycles, following extraction. Extracts were stable for ≥ 9 days when kept in
239 the autosampler at 15 °C. (Table 3).

240 **3.2.3 Selectivity and specificity**

241 In all, 9 molecules were tested, including immunosuppressants (everolimus and
242 sirolimus), antifungals (posaconazole and voriconazole), antivirals (aciclovir and ganciclovir),
243 tyrosine kinase inhibitors (ribociclib and palbociclib), and tamoxifen. None presented a peak
244 area >20% of that for G1 or the IS peak.

245 **3.2.4 Lower and upper limits of quantification**

246 LLOQs were 0.4 ng/mL for ANA, 0.3 ng/mL for LET, 0.8 ng/mL for EXE, and
247 1 ng/mL for FUL, each LLOQ corresponding to the lowest concentration with a CV of <20%
248 and an accuracy of 80%–120%. ULOQs were 150 ng/mL for ANA, 1,000 ng/mL for
249 LET, 200 ng/mL for EXE and 400 ng/mL for FUL, each ULOQ corresponding to the highest
250 concentration with a CV of <15% and an accuracy of 95%–115%.

251 **3.2.5 Linearity**

252 Calibration curve equations for the 4 analytes are given in **Table 1**. Coefficients of
253 correlation (r^2) were all >0.9900 . Calibrator CVs were $\leq 10.54\%$ and accuracy was 95.28% –
254 107.02% (**Table 4**).

255 **3.2.6 Matrix effect, hemolysis effect, and extraction recovery**

256 Plasma of patients treated with four different drug classes were selected: antivirals
257 (ganciclovir and aciclovir), immunosuppressants (everolimus and sirolimus), antifungals
258 (posaconazole and itraconazole), and lastly, a tyrosine kinase inhibitor (ribociclib). No
259 significant matrix effect was observed. Matrix effect ranges were 82.7% – 108.1% (QC1) and
260 92.1% – 112.1% (QC3) for ANA; 88.4% – 106.5% (QC1) and 90.1% – 110.1% (QC3) for LET;
261 81.3% – 117.5% (QC1) and 91.6% – 105.2% (QC3) for EXE; 86.9% – 120.7% (QC1) and
262 87.0% – 112.9% (QC3) for FUL. Mean matrix effects for each analyte are given in **Table 5**.
263 IS-normalized matrix factor CVs were 2.32% (QC1) and 2.46% (QC3) for ANA; 9.21%
264 (QC1) and 1.72% (QC3) for LET; 4.84% (QC1) and 1.99% (QC3) for EXE; and 6.51%
265 (QC1) and 1.52% (QC3) for FUL.

266 Concentrations of QC1 and QC3 samples prepared with 2% hemolyzed plasma did not
267 diverge by $>15\%$ from the QC1 and QC3 samples prepared with blank plasma. Hence, 2%-
268 hemolyzed plasma did not appear to interfere with analyte quantification.

269 Extraction recovery data are provided in **Table 5**. CVs varied from -6.08% to 15.43%
270 with all analytes except EXE, for which CVs were homogenous for all 3 concentrations but
271 varied from 20.33% to 23.78% . Considering the linearity, accuracy, and precision of
272 calibrator standards, no correction factor was applied for EXE quantification.

273 **3.2.7 Carryover**

274 No carryover was observed for any of the 4 analytes. Carryover percentages were all
275 <0.112%. Furthermore, no G1 peak area exceeded 20% of the reference peak area and 5% of
276 the reference IS peak area.

277 **3.2.8 Dilution integrity**

278 Both spiked and diluted samples were within the acceptable range of 15% for the
279 4 analytes (**Table 6**). Samples with a concentration exceeding the calibration range can thus
280 be diluted.

281 **3.3 Clinical application**

282 All patient plasma samples lay within the validated calibration range for this method:
283 10.6–283.3 ng/mL for LET, 1.1–2.4 ng/mL for EXE, and 13.9 – 33.0 ng/mL for FUL. Patients
284 were all treated with combination therapies representative of clinical practice. **Figure 2**
285 presents analyte concentration ranges, excluding patients with plasma concentrations below
286 LLOQ. There was no observed interference related to other drugs taken by patients.

287 **4 Discussion**

288 In this study, we describe a method for the simultaneous quantification of ANA, LET,
289 EXE, and FUL in patient plasma samples for therapeutic drug monitoring, and for clinical
290 research, to assess potential adverse effects of these 4 hormone therapy drugs.

291 Recent combination therapies involve the association of AIs or antiestrogens with
292 other treatments, such as ribociclib, a TKI [19-22] which may causes cardiometabolic
293 disorders. Quantification of these drugs may reduce the likelihood of adverse effects.

294 Several LC-MS/MS methods have been proposed in the literature for quantifying one
295 or more hormone therapy drugs. To the best of our knowledge, however, no other method
296 simultaneously quantifies ANA, LET, EXE, and FUL.

297 Matrix effect and hemolysis effect were tested, and the results were satisfying
298 according to the guidelines of the FDA. No carryover was observed, and we are similar to
299 another study that attempted to use a rinsing solution consisting of 50% methanol to eliminate
300 the carryover they encountered at the beginning of the method validation for the following
301 molecules, anastrozole and fulvestrant. Our rinsing solution is composed of 100% MeOH.
302 The extraction recovery was satisfying and the results was similar to this studie [8].

303 For the quantification of FUL in human plasma, Turkovic et al. [23] successfully
304 validated a LC-MS/MS method with a range of 5–1,000 ng/mL. Despite the limited number
305 of samples in our study, the average concentration was found to be 21 ng/mL, with one outlier
306 at 33 ng/mL. In contrast, Van Nuland et al. [24] reported low sensitivity with their method,
307 necessitating an additional concentration step for sample extraction when dealing with EXE,
308 along with a relatively large sample volume of 500 μ L. Our method permits rapid processing
309 with short sample preparation and run times (4 min), requires a minimal plasma volume of
310 50 μ L, and boasts wider ranges (**Table 7**).

311 For their clinical study, Beer et al. [8] reported concentration ranges of 6.2–102.0
312 ng/mL (mean: 37.4 ng/mL) for ANA and 17.0–301.3 ng/mL (mean: 107 ng/mL) for LET. The
313 study revealed significant interindividual variability for these concentrations. Importantly,
314 these ranges are well within the linear ranges validated for our own method. As such, the
315 measured plasma concentrations and those reported in the literature did not provide any
316 compelling reason to further extend our current measurement ranges.

317 In previous research [25, 26], the maximum length of time for assessing short-term
318 stability of the 4 molecules was 5 days. However, our results suggest that these analytes

319 remain stable for longer periods: up to 7days at room temperature and up to 15days when
320 refrigerated at 4 °C. The long-term stability of ANA, EXE, and LET was considered by a
321 previously published method, which confirmed that the molecules remained stable over a
322 period of 21 weeks. Our study demonstrated their stability over a period of 3 months at
323 -20 °C.

324 Limitations we faced included certain methodological constraints that hindered our
325 ability to measure the metabolites of the 4 hormone therapy drugs as well as a lack of plasma
326 samples from patients being treated with ANA.

327 **5 Conclusions**

328 In summary, we have developed and validated a quantitative method for therapeutic
329 monitoring of ANA, LET, EXE, and FUL. Sample treatment is easy and effective, requiring
330 only one simple precipitation. We have shown that small sample volumes are suitable for
331 routine quantification of these analytes. The validated ranges include measured
332 concentrations in patient plasma samples are aimed to be applied in wider and more diverse
333 groups of patients and with the intention of describing eventual mechanisms to
334 interindividual/intraindividual plasma variations. However, we encountered certain
335 limitations, such as the scarcity of plasma samples from patients treated with those four drugs,
336 especially anastrozole, and the lack of chemical reagents to expand our measurements and
337 quantify the metabolites of the four analytes. This method could also apply to
338 pharmacokinetic/pharmacodynamic studies and clinical trials

339 **Acknowledgments:** None.

340 **Author contributions:** B.M, C.N: investigation, validation, data analysis, visualization,
341 writing-original draft, writing-review and editing. D.S, P.R, J.B, C.M, G.N, A.P, M.J,
342 J.G,J.S : investigation, writing-review and editing. N.Z: supervision, conceptualization,

343 validation, visualization, investigation, writing-original draft ,writing-review and editing. All
344 authors have accepted responsibility for the entire content of this manuscript and approved its
345 submission.

346 **Declaration of Competing Interest** The authors declare that they have no known competing
347 financial interests or personal relationships that could have appeared to influence the work
348 reported in this paper.

349

350

351

352

353

354

355

356

357

358

359

360

361

362

363

364

365

366

367 **6 References**

- 368 1. <https://www.e-cancer.fr/Patients-et-proches/Les-cancers/Cancer-du-sein/Quelques-chiffres>.
- 369 2. Ozdemir, B.C., G. Sflomos, and C. Brisken, *The challenges of modeling hormone receptor-*
370 *positive breast cancer in mice*. *Endocr Relat Cancer*, 2018. **25**(5): p. R319-R330.
- 371 3. Lonning, P.E., *The potency and clinical efficacy of aromatase inhibitors across the breast*
372 *cancer continuum*. *Ann Oncol*, 2011. **22**(3): p. 503-514.
- 373 4. Mukherjee, A.G., et al., *Letrozole: Pharmacology, toxicity and potential therapeutic effects*.
374 *Life Sci*, 2022. **310**: p. 121074.
- 375 5. Groenland, S.L., et al., *Therapeutic Drug Monitoring of Oral Anti-Hormonal Drugs in*
376 *Oncology*. *Clin Pharmacokinet*, 2019. **58**(3): p. 299-308.
- 377 6. Bertelsen, B.E., et al., *Simultaneous Quantification of Aromatase Inhibitors and Estrogens in*
378 *Postmenopausal Breast Cancer Patients*. *J Clin Endocrinol Metab*, 2022. **107**(5): p. 1368-1374.
- 379 7. McCormack, P. and F. Sapunar, *Pharmacokinetic profile of the fulvestrant loading dose*
380 *regimen in postmenopausal women with hormone receptor-positive advanced breast cancer*.
381 *Clin Breast Cancer*, 2008. **8**(4): p. 347-51.
- 382 8. Beer, B., et al., *Development and validation of a liquid chromatography-tandem mass*
383 *spectrometry method for the simultaneous quantification of tamoxifen, anastrozole, and*
384 *letrozole in human plasma and its application to a clinical study*. *Anal Bioanal Chem*, 2010.
385 **398**(4): p. 1791-800.
- 386 9. Cuzick, J., et al., *Effect of anastrozole and tamoxifen as adjuvant treatment for early-stage*
387 *breast cancer: 10-year analysis of the ATAC trial*. *Lancet Oncol*, 2010. **11**(12): p. 1135-41.
- 388 10. Nabholz, J.M., *Long-term safety of aromatase inhibitors in the treatment of breast cancer*.
389 *Ther Clin Risk Manag*, 2008. **4**(1): p. 189-204.
- 390 11. Plourde, P.V., M. Dyroff, and M. Dukes, *Arimidex: a potent and selective fourth-generation*
391 *aromatase inhibitor*. *Breast Cancer Res Treat*, 1994. **30**(1): p. 103-11.
- 392 12. Ingle, J.N., et al., *Estrogens and their precursors in postmenopausal women with early breast*
393 *cancer receiving anastrozole*. *Steroids*, 2015. **99**(Pt A): p. 32-8.
- 394 13. [https://www.accessdata.fda.gov/drugsatfda_docs/nda/99/20-](https://www.accessdata.fda.gov/drugsatfda_docs/nda/99/20-753_Aromasin_biopharmr_P1.pdf)
395 [753_Aromasin_biopharmr_P1.pdf](https://www.accessdata.fda.gov/drugsatfda_docs/nda/99/20-753_Aromasin_biopharmr_P1.pdf).
- 396 14. Robertson, J.F. and M. Harrison, *Fulvestrant: pharmacokinetics and pharmacology*. *Br J*
397 *Cancer*, 2004. **90** Suppl 1(Suppl 1): p. S7-10.
- 398 15. [https://www.fda.gov/regulatory-information/search-fda-guidance-documents/m10-](https://www.fda.gov/regulatory-information/search-fda-guidance-documents/m10-bioanalytical-method-validation-and-study-sample-analysis)
399 [bioanalytical-method-validation-and-study-sample-analysis](https://www.fda.gov/regulatory-information/search-fda-guidance-documents/m10-bioanalytical-method-validation-and-study-sample-analysis).
- 400 16. [https://www.ema.europa.eu/en/documents/scientific-guideline/guideline-bioanalytical-](https://www.ema.europa.eu/en/documents/scientific-guideline/guideline-bioanalytical-method-validation_en.pdf)
401 [method-validation_en.pdf](https://www.ema.europa.eu/en/documents/scientific-guideline/guideline-bioanalytical-method-validation_en.pdf).
- 402 17. [https://www.ema.europa.eu/en/documents/scientific-guideline/ich-guideline-m10-](https://www.ema.europa.eu/en/documents/scientific-guideline/ich-guideline-m10-bioanalytical-method-validation-step-5_en.pdf)
403 [bioanalytical-method-validation-step-5_en.pdf](https://www.ema.europa.eu/en/documents/scientific-guideline/ich-guideline-m10-bioanalytical-method-validation-step-5_en.pdf).
- 404 18. D'Cunha, R., et al., *Quantification of Cefepime, Meropenem, Piperacillin, and Tazobactam in*
405 *Human Plasma Using a Sensitive and Robust Liquid Chromatography-Tandem Mass*
406 *Spectrometry Method, Part 1: Assay Development and Validation*. *Antimicrob Agents*
407 *Chemother*, 2018. **62**(9).
- 408 19. Park, Y.H., et al., *Palbociclib plus exemestane with gonadotropin-releasing hormone agonist*
409 *versus capecitabine in premenopausal women with hormone receptor-positive, HER2-*
410 *negative metastatic breast cancer (KCSG-BR15-10): a multicentre, open-label, randomised,*
411 *phase 2 trial*. *Lancet Oncol*, 2019. **20**(12): p. 1750-1759.
- 412 20. Kapagan, T., et al., *Ribociclib-induced visual hallucination in a patient with metastatic breast*
413 *cancer*. *J Oncol Pharm Pract*, 2023. **29**(6): p. 1529-1532.
- 414 21. Kahraman, S., et al., *Treatment efficacy of ribociclib or palbociclib plus letrozole in hormone*
415 *receptor-positive/HER2-negative metastatic breast cancer*. *Future Oncol*, 2023. **19**(10): p.
416 727-736.

- 417 22. Salem, J.E., et al., *Anticancer drug-induced life-threatening ventricular arrhythmias: a World*
418 *Health Organization pharmacovigilance study*. Eur Heart J, 2021. **42**(38): p. 3915-3928.
- 419 23. Turkovic, L., et al., *Development and Validation of a Novel LC-MS/MS Method for the*
420 *Simultaneous Determination of Abemaciclib, Palbociclib, Ribociclib, Anastrozole, Letrozole,*
421 *and Fulvestrant in Plasma Samples: A Prerequisite for Personalized Breast Cancer Treatment*.
422 Pharmaceuticals (Basel), 2022. **15**(5).
- 423 24. van Nuland, M., et al., *Development and validation of an UPLC-MS/MS method for the*
424 *therapeutic drug monitoring of oral anti-hormonal drugs in oncology*. J Chromatogr B Analyt
425 Technol Biomed Life Sci, 2019. **1106-1107**: p. 26-34.
- 426 25. Balaram, V.M., et al., *Sensitive and rapid high-performance liquid chromatography tandem*
427 *mass spectrometry method for estimation of fulvestrant in rabbit plasma*. Biomed
428 Chromatogr, 2010. **24**(8): p. 863-7.
- 429 26. Mendes, G.D., et al., *Anastrozole quantification in human plasma by high-performance liquid*
430 *chromatography coupled to photospray tandem mass spectrometry applied to*
431 *pharmacokinetic studies*. J Chromatogr B Analyt Technol Biomed Life Sci, 2007. **850**(1-2): p.
432 553-9.
- 433