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Trace determination of gatifloxacin in pharmaceutical and biological samples using hydrophobic magnetic nanoparticles-assisted ionic liquid microextraction coupled with spectrofluorimetry

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ABSTRACT

A simple and rapid microextraction procedure based on the application of magnetic nanoparticles and hydrophobic 1-Hexylpyridinium hexafluorophosphate [Hpy][PF6] ionic liquid (IL) was applied to trace determination of gatifloxacin. A mixture of [Hpy][PF_6] and magnetic nanoparticles was injected into the sample solution containing the analyse of interest and a cloudy solution was formed. After centrifuging, the sediment phase containing enriched analyse was determined by spectrofluorimetry. Magnetic nanoparticles used in this microextraction procedure significantly improved the extraction recovery which is due to its proper hydrophobicity. [Hpy][PF_6] was used as the extraction solvent due to some physicochemical properties such as high hydrophobicity, water immiscibility and quite viscosity. Under optimum experimental conditions, the proposed method provided a limit of detection (LOD) of 0.09 µg L^{-1} and a relative standard deviation (R.S.D.) of 3.0%. The present technique was applied to gatifloxacin determination in pharmaceutical formulations and human urine.

Keywords: *Ionic liquid; Microextraction; Magnetic nanoparticles; Gatifloxacin; Spectrofluorimeter; Pharmaceutical.*

INTRODUCTION

Gatifloxacin (GFLX), (±)-1-cyclopropyl-6-fluoro-1,4-dihydro-8-methoxy-7-(3-methyl-1-piperazinyl)-4-oxo-3-quinoline carboxylic acid (Figure 1) is the fourth generation of a new class of synthetic antibacterial fluoroquinolone agents. It is a novel extended spectrum fluoroquinolone with an improved Gram positive and anaerobe coverage compared with older agents such as ciprofloxacin. Different analytical methods have been proposed for quantitative analysis of gatifloxacin in real samples.

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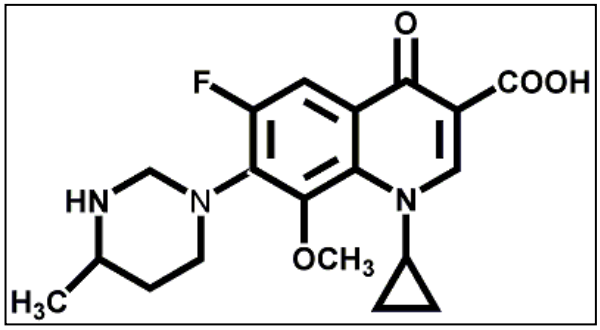

Fig.1. Chemical structure of gatifloxacin.

These techniques include spectrofluorimetry, polarography, voltammetry, chemiluminescence, and high performance liquid chromatography (HPLC) [1-5]. Sample pretreatment is an important step to isolate the compound of interest from the sample matrix, as well as to increase the concentration of analytes prior to their quantitative analysis.

Ionic liquids (ILs) have excellent chemical and physical properties such as low vapor pressure, excellent thermal stabilities, adjustable miscibility, moderate solubility of organic compounds and metal ions, etc., which make them highly practical in sample pretreatment methods [6]. To completely remove hazardous materials in pretreatment methods, ILs have been widely used in microextraction methods as green solvents [7-15].

The use of sample preparation steps based on ILs offers various advantages like excellent recovery, no need of hazardous materials, simplicity and compatibility with many analytical methods. Based on the results obtained in our previous study, the application of nanoparticles in extraction procedure significantly improves the extraction recovery which is due to their hydrophobic behaviors [16]. In the proposed work, a mixture of hydrophobic pyridinium IL and magnetic nanoparticles was injected into the aqueous sample solution in order to extract the analyte of interest.

[Hpy][PF_6] was applied as the microextraction phase because of some physicochemical properties including proper hydrophobicity, water immiscibility and desired density. The proposed technique does not need heating, anti-sticking agent, long equilibration time and cooling before or after centrifugation prior to quantitative analysis. To our knowledge, until now, no technique based on the extraction with ILs and magnetic nanoparticles and spectrofluorimetric detection has been applied for determination of drugs. Spectrofluorimetric technique was used due to ease, excellent selectivity and sensitivity, proper dynamic range and low cost of equipment.

In this study, hydrophobic magnetic nanoparticles-assisted ionic liquid microextraction was combined with spectrofluorimetry for the determination of gatifloxacin in real samples. The procedure described provides an interesting and innovative approach of combining microscale sample preparation and analytical techniques to solve quantitative analysis problems.

EXPERIMENTAL

Material and methods

All reagents were of analytical-reagent grade. 1-Hexylpyridinium hexafluorophosphate [Hpy][PF_6] (97%) (Across organics, Belgium) was used as a microextraction solvent. Acetone, acetonitrile, methanol and ethanol were purchased from Merck (Darmstadt, Germany). Stock solution of gatifloxacin at concentration of 1000 mg L^{-1} was obtained by dissolving the required amount of pure drug in pure water, and working standard solutions were prepared using serial dilutions of this stock solution. [HPy][PF_6] IL is not liquid at room temperature (melting point: 45 °C). Therefore, this IL was dissolved in acetonitrile to achieve a working solution of 75 mg mL^{-1}. We used 0.5 mol L^{-1} of sodium hydroxide and concentrated hydrochloric acid, for adjusting the pH value of sample solutions. Gatifloxacin tablets (labeled as containing 200 and 300 mg gatifloxacin per tablet) were obtained from commercial sources.

Fluorescence spectra were recorded using a Perkin-Elmer LS 50 spectrofluorimeter equipped with xenon discharge lamp, and quartz micro-cell with a volume of 100 µL. A centrifuge from Hettich (Tuttlingen, Germany) was applied to accelerate the phase separation process. An adjustable sampler (10-100 µL) was obtained from Eppendorf (Hamburg, Germany). The pH-meter model 692 (Herisau, Switzerland) supplied with a glass-combined electrode and universal pH

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indicator (pH 0-14) from Merck (Darmstadt, Germany) were used for the pH measurements.

Synthesis of magnetic nanoparticles

$FeCl_3 \cdot 6H_2O$ (1.35 g), ethylene glycol (40 mL), sodium acetate (3.6 g), and polyethylene glycol (1.2 g) were completely mixed and reacted in an oven at 200 °C for 5 h. Then, the obtained product was washed four times with 30 mL ethanol and afterwards was calcinated at 300 °C for 4 h. Surface modification of the nanoparticles was performed as follows: 0.2 g of magnetic nanoparticles, 0.5 g of 3-chloropropyltriethoxysilane, and 10 mL of anhydrous toluene were swirled for 15 min under a nitrogen atmosphere. The mixture was transferred into an autoclave in order to react at 100 °C for 7 h. Then, the obtained particles were washed with toluene and methanol in sequence. After the final step, the particles were dried before use.

Characterization of the nanoparticles

The fabricated nanoparticles were characterized by scanning electron microscopy (SEM) (Figure 2). A JSM-6701F SEM system (JEOL, Tokyo, Japan) was applied for observation of the nanoparticles. The sample was fixed on the stub by a double-sided sticky tape and then coated with platinum by a JFC-1600 (JEOL) Auto fine coater for 30 s.

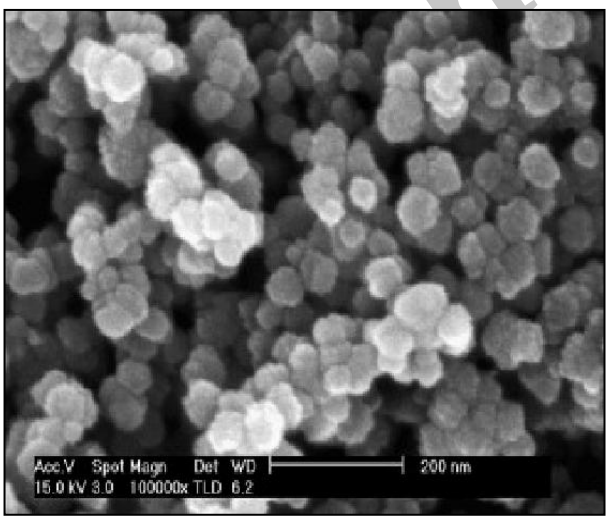

Fig. 1. SEM image of hydrophobic magnetic nanoparticles

General analytical procedure

10.0 mL sample or standard solution (pH 5) containing gatifloxacin in the range of 0.6 to 80 µg L^{-1} was transferred into a test tube with conic bottom. Then, 95 mg of $[HPy][PF_6]$ (dissolved in acetonitrile) containing 5 mg magnetic nanoparticles was added to the sample solution. In order to accelerate phase separation, the obtained solution was centrifuged for 5 min at 4000 rpm. The upper aqueous solution was then removed by decanting. Then, a magnet was held to the bottom of the test tube in order to attract and isolate the magnetic nanoparticles. After this step, a magnet was held to the bottom of the test tube in order to attract and isolate the magnetic nanoparticles. Afterwards, the magnet was removed, and 200 µL of acetonitrile was added to the tube to desorb the gatifloxacin from the nanoparticles by sonication for 4 min. Finally, the magnet was again placed to the bottom of the test tube, and 100 µL of the upper solution was collected using a sampler and transferred into the micro-cell of spectrofluorimeter. The fluorescence intensity was measured at 485 nm with the excitation wavelength set at 298 nm.

Analysis of tablets

Four gatifloxacin tablets, labeled as containing 200 mg gatifloxacin each, were accurately weighed and the average mass per tablet was determined. An amount of the powder equivalent to 2 mg of gatifloxacin was weighed and dissolved in 50 mL pure water. The solution was filtered and treated according to general analytical procedure.

Analysis of spiked human urine

Fresh human urine (10 mL) was placed into centrifuge tubes. The solutions were centrifuged for 5 min at 4000 rpm. Then, aliquots of 2 mL from clear supernatant were transferred into new centrifuge tubes and spiked with different amounts of gatifloxacin (5 to 60 µg L^{-1}). Afterwards, the general analytical procedure was followed.

RESULTS AND DISCUSSION

In this study, an efficient and simple magnetic nanoparticles-assisted ionic liquid microextraction method was combined with

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spectrofluorimetry for preconcentration and determination of gatifloxacin. By using nanoparticles, the microextraction recovery improved which was due to their hydrophobic behaviors. In order to obtain the best extraction recovery, influence of different parameters affecting the microextraction system were studied in details and optimized.

Spectral characteristics of gatifloxacin and ionic liquid

Gatifloxacin shows intense fluorescence which is due to its cyclic conjugated structure which benefits of having π-electron system. The emission spectra of the drug under study were recorded as described in the general analytical procedure. The emission peak of gatifloxacin is at 485 nm, while its excitation peak is at 298 nm (Figure 3). To obtain accurate and sensitive fluorescence intensity, it is important to study the effect of the reagent blank on fluorescence spectrum of the analyte. For this goal, fluorescence spectrum of the reagent blank was recorded. As it can be seen in Figure 3, the emission of [HPy][PF_6] has no appreciable effect on the determination of gatifloxacin. Thus, the aforementioned wavelengths were chosen for all experiments.

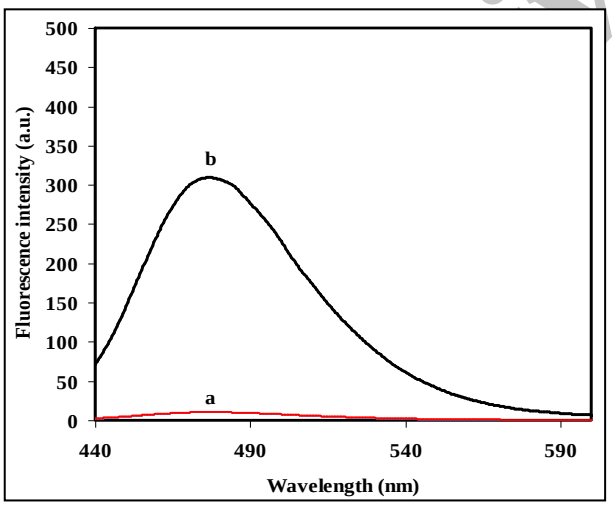

Fig. 3. Emission spectrum of gatifloxacin (80 µg L^{-1}) treated the same as previously described in the general analytical procedure (a), and emission spectrum of reagent blank in [Hpy][PF_6] ionic liquid (b).

Influence of IL amount

The amount of [HPy][PF_6] is a important factor which can affect the sensitivity of the hydrophobic magnetic nanoparticles-assisted ionic liquid microextraction. So, the sample preparation system was exactly investigated in order to obtain a compromise between the IL amount and the analytical sensitivity. The Effect of [HPy][PF_6] amount on the analytical performance was studied within the range of 25-120 mg. Figure 4 shows the variation of the fluorescence intensity versus the amount of IL. As it can be ascertained, the analytical signal increases as the amount of [HPy][PF_6] increases, and remains approximately stable from 95 mg. No meaningful variations were obtained on the microextraction performance for higher amounts of IL. As a result, in order to achieve sensitive analytical response, 95 mg of IL was chosen as an optimum value.

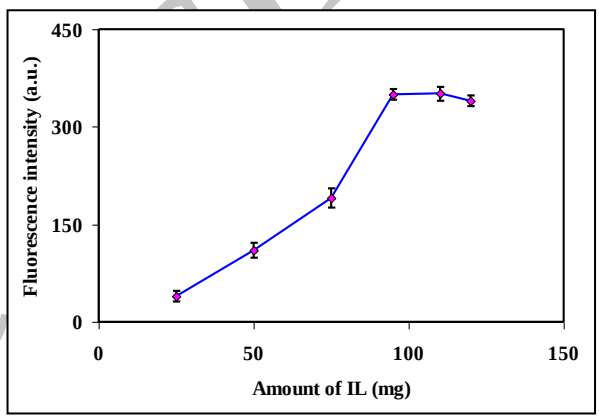

Fig. 4. Effect of amount of [Hpy][PF_6] on the analytical responses. Experimental conditions: gatifloxacin concentration 50 µg L^{-1}; pH 5; magnetic nanoparticles 5 mg

Influence of pH

The influence of pH on the hydrophobic magnetic nanoparticles-assisted ionic liquid microextraction of gatifloxacin was investigated in the range of 1.0–13.0. The obtained results revealed that the maximum analytical intensity can be obtained at pH 5.0 (Figure 5). However, the fluorescence intensity decreased as the pH increased further. Hence, pH 5.0 was selected for the rest of the work.

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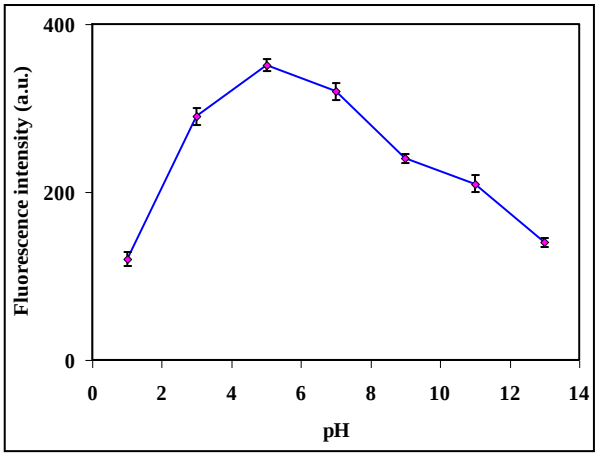

Fig. 5. Effect of pH on the fluorescence intensities. Experimental conditions: gatifloxacin concentration 50 µg L^{-1}; [Hpy][PF_6] 95 mg; magnetic nanoparticles 5 mg;

Influence of equilibration temperature and extraction time

To obtain complete microextraction of gatifloxacin and easy phase separation, the influence of extraction temperature was evaluated from 10 to 40 °C. Based on the results obtained in this study, the temperature had no meaningful and practical effect on the extraction performance. As a result, room temperature as an equilibration temperature was applied for the rest of the work. Microextraction time is one of the important factors which significantly affect the microextraction efficiency. The dependence of extraction performance upon extraction time was carefully tested from 5 sec to 30 min. The results of this experiment revealed that analytical signal variations versus extraction time did not show significant manner. It was well documented that after formation of the cloudy solution, the surface area between extraction solvent phase and aqueous phase was appreciably large. Thus, the transfer of the target analyte from aqueous media to extractor was very fast. To keep microextraction time as short as possible, the cloudy solution was centrifuged rapidly after creation.

Influence of centrifugation condition

In this experiment, the influence of centrifugation rate on the fluorescence signal was evaluated from 1000 to 5000 rpm. The results obtained in this study showed that over 3500 rpm the IL-phase was entirely transferred to the bottom of the tube, and the analytical response remained constant. Thus, 4000 rpm was selected for the rest of the work. At the optimum selected rate, the effect of centrifugation time upon analytical responses was tested within the range of 1-15 min. Over 4 min, no significant changes in analytical responses was observed which it showed complete transfer of IL-phase to the bottom of the centrifuge conical test tube. Therefore, a centrifugation time of 5 min was selected as the optimum value and it was used for all experiments.

Influence of ionic strength

In the present study, influence of ionic strength on the fluorescence intensity was tested by adding different amounts of NaCl from 0 to 10% (w/v). In this experiment, other parameters were kept constant (see Figure 6). No significant changes were observed within the studied ionic strength range.

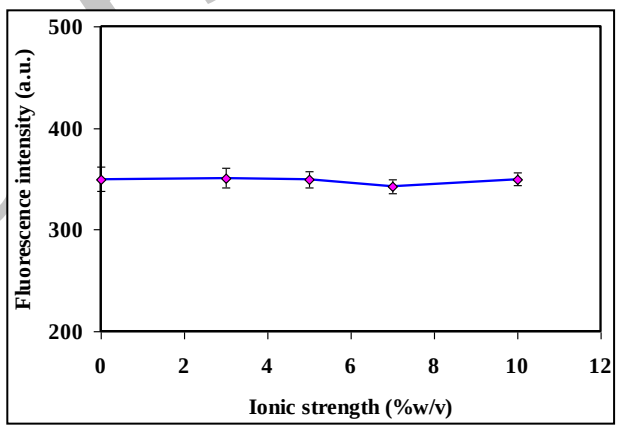

Fig. 6. Effect of ionic strength on the analytical signals. Experimental conditions: gatifloxacin concentration 50 µg L^{-1}; [Hpy][PF_6] 95 mg; pH 5; magnetic nanoparticles 5 mg.

Influence of magnetic nanoparticles amount

Effect of magnetic nanoparticles amount on the analytical responses was evaluated with the range of 1-10 mg. based on the results obtained in this study, the extraction recovery increases as the amount of nanoparticles increases, which is due to their hydrophobic behaviors, and after 5 mg, extraction recovery reaches to an approximately stable value. Hence, 5 mg of nanoparticles was selected as the optimum value.

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Influence of interfering substances

In this experiment, the selectivity of the proposed system was tested. For this goal, the influence of some chemical species on the quantitation of target analyte was studied by analyzing solutions containing 50 µg L^{-1} of gatifloxacin, and adding 50 mg L^{-1} of the potentially interfering materials. The tolerance limit of each interfering substance was taken into account as the largest amount yields an error in the determination of the target analyte which not exceed 4.5%. No critical interference was observed from commonly interfering materials such as Na^{+}, NH_4^{+}, Ca^{2+}, Zn^{2+}, Mg^{2+}, Cl^{-}, PO_4^{3-}, SO_4^{2-}, starch, glucose, lactose, fructose, sucrose, ascorbic acid, citric acid, dye species (as yellow quinoline), urea, and saccharin. The obtained results showed the appreciable selectivity of the proposed combined methodology in detecting the studied drug in real samples.

Applications

- **Analytical performance**

In the proposed method, calibration graph was achieved by analyzing 10.0 mL of standard solutions containing known amounts of gatifloxacin. The settled phase was diluted to 200 µL with acetonitrile and the fluorescence intensity was measured. Thus, a preconcentration factor of 50 was achieved. Analytical characteristic of the proposed combined methodology are shown in Table 1. The limit of detection (LOD), calculated as three times the standard deviation of the measurement of blanks divided by the slope of the calibration curve, was found to be 0.09 µg L^{-1}.

Table 1. Analytical characteristics of magnetic nanoparticles-assisted ionic liquid microextraction-spectrofluorimetry for the determination of gatifloxacin.

Parameter	Analytical feature
Linear range (µg L^{-1})	0.6-80
Correlation coefficient (R^2)	0.9981
Limit of detection (µg L^{-1})	0.09
Repeatability (R.S.D.[a], %) (n = 5)	3.0
Preconcentration factor (PF)	50
Sample volume (mL)	10
Extraction time (min)	<6

[a] R.S.D. was obtained for the determination of five replicates of 50 µg L^{-1} gatifloxacin.

- **Analysis of gatifloxacin in pharmaceutical formulations**

To demonstrate the validity of the proposed magnetic nanoparticles-assisted ionic liquid microextraction coupled with spectrofluorimetry, it was applied for gatifloxacin determination in commercial formulations. Three replicate determinations were carried out, and satisfactory results were achieved. Table 2 shows the results obtained by using the present methodology and those obtained by a reported method [4]. The results show the applicability of the proposed methodology for determination of gatifloxacin in pharmaceutical samples.

Table 2. Determination of gatifloxacin in tablets by the proposed methodology and by a reported method [4].

Claimed (mg/tablet)	Proposed methodology (mg)[a]	Reported method (mg)[a]	Error (%)[b]	Error (%)[c]
200	191.2 ± 6.0	202.5 ± 4.3	-4.4	-5.5
300	306.0 ± 9.1	309.8 ± 4.6	+2.0	-1.2

[a] Standard deviations are based on three replicates.
[b] Error against the declared value.
[c] Error against the reported method.

- **Analysis of gatifloxacin in human urine**

The proposed method was applied for determination of gatifloxacin in spiked human urine, in order to show the accuracy of the present method. The recovery of the studied drug was investigated at four concentration levels. The obtained results are shown in Table 3. As can be seen, calculated amounts of recoveries varied between 91.9-105.0% for human urine indicating both accuracy and precision. In addition, these results show that one the major advantages of the present method is that the determination of gatifloxacin in human urine samples can be made by direct comparison with aqueous standard solution.

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Table 3. Determination of gatifloxacin in spiked human urine by present work.

Drug	Spiked urine		
	Amount added (μg L^{-1})	Amount found (μg L^{-1}) ± S.D.[a]	Recovery (%)
Gatifloxacin	5	4.82 ± 0.17	96.4
	10	9.19 ± 0.41	91.9
	20	21.0 ± 0.9	105.0
	60	62.3 ± 2.8	103.8

CONCLUSIONS

A novel and efficient mode of microextraction based on the application of ionic liquid and magnetic nanoparticles was combined with spectrofluorimetry to preconcentrate and determine trace levels of gatifloxacin. Hydrophobic [Hpy][PF_6] ionic liquid was selected as a green microextraction solvent and an alternative to traditional toxic volatile organic solvents. Due to the hydrophobic behaviors of magnetic nanoparticles used in this work, the extraction recoveries significantly improved. The proposed methodology was demonstrated to be sensitive, selective, fast, efficient, inexpensive and environmentally friendly for preconcentration, determination and separation of the trace analytes. Furthermore, the proposed methodology revealed to be an efficient tool for routine quality control of drugs in pharmaceutical and urine samples with low operation cost and simplicity of instrumentation.

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