ELSEVIER

Journal of Chromatography B, 740 (2000) 227–236

JOURNAL OF CHROMATOGRAPHY B

www.elsevier.com/locate/chromb

Analysis of corticosteroids in hair by liquid chromatography–electrospray ionization mass spectrometry

Fabien Bévalot[a,*], Yvan Gaillard[a], Michel A. Lhermitte[b], Gilbert Pépin[a]

[a]*Laboratoire d'Expertises TOXLAB, 18 Rue André Del Sarte, 75018 Paris, France*
[b]*Hôpital Calmette, Laboratoire de Biochimie, Rue du professeur Leclercq, 59045 Lille, France*

Received 24 April 1999; received in revised form 11 January 2000; accepted 31 January 2000

Abstract

The present study describes a confirmatory method for the quantitative determination in hair of the most common corticosteroids illegaly used as doping agents by athletes. Corticosteroids are extracted from 50 mg of powdered hairs by methanolic extraction follows by a solid-phase extraction on C_{18} cartridge. After extraction, the dried residue is reconstituted with 50 μl acetonitrile and injected in a liquid chromatograph. Liquid chromatography separation is performed on a reversed-phase C_{18} column with a binary gradient of formiate buffer pH 3-acetonitrile as mobile phase. Detection is performed with an electrospray ionization mass spectrometer in negative ion and selected-ion monitoring mode. The limits of sensitivity achieved is 0.1 ng/mg in hair. Application to hair sample collected during an antidoping control and comparison to results obtain on urines, collected on the same athletes at the same time, shows the interest and the complementarity of both matrices. Hair analysis could allow the detection of corticosteroids on a large period preceding the control, and the detection of natural corticosteroids administered as pro-drug, like hydrocortisone acetate.

Keywords: Corticosteroids; Doping control; Hair analysis

1. Introduction

Cortisone, and hydrocortisone are naturally occurring steroidian hormones which are synthesized in the adrenal cortex. They influence many physiological mechanisms: carbohydrate, protein, and lipid metabolism, inflammation, electrolyte and water balance... Their analogues and synthetic derivatives are used in therapeutic, particularly for their anti-inflammatory and immunosuppressive actions, or for substitution therapy in the case of insufficiency of adrenal cortex secretion. In addition to these legal indications, they are used in certain sports to improve the performances of athletes. The expected effect would be in that case a certain euphoria, and an increase in motor activity. Administration of these substances per general route is prohibited by the International Olympic Committee (IOC), while their use under local presentations is subjected to restrictions [1,2]. Current antidoping controls are carried out on the urines. Corticosteroids can be detected in this matrix between 10 and 36 h after administration, depending on the technique of analysis and the

*Corresponding author. Laboratoire de Pharmacologie, Hôpital d'Instruction des Armées Desgenettes, 108 Boulevard Pinel, 69275 Lyon Cédex 3, France. Fax: +33-472-3661.
E-mail address: bevalot@aol.com (F. Bévalot)

0378-4347/00/$ – see front matter
PII: S0378-4347(00)00085-2

molecule. Triamcinolone acetonide can be detected for a few days [3]. Hair analysis makes it possible to go up further in time, since the integration of xenobiotic is done partly during the histogenesis of the hair. Analysis of such a sample makes it possible to cover a period dependent on the length of the hair (grow rate is 1 cm per month on average). The pubic or axillary hair can also be used. It is then possible to detect an early and repeated doping, which has become undetectable in urines, it also avoids any risk of adulteration. Studies on hair were done on molecules belonging to the majority of the classes of doping substances, or subjected to restrictions by the IOC. One can quote among the stimulants and psychotropes: amphetamines and derivatives [4–9], cocaine [10–12], cannabinoids [13–15], ephedrin [16], phencyclidine [17] and among narcotics: the opiates and derivatives [9,18–26]. Clenbuterol, which is used as a stimulant by athletes, was highlighted in calf hair [27], an animal in which Clenbuterol is used illegally to increase the muscular mass. Stanozolol, an anabolic steroid, has been the subject of a study on rat hair [28]. Other anabolic steroids have been recently studied: nandrolone (and ester), boldenone, testosterone (and esters), ethinyl estradiol, and metandienone. Interest in meat quality control and doping control has been demonstrated for these molecules [29]. Lidocaïne, a local anesthetic, has been found in the hair of a person who used the drug during repeated episodes of self-mutilation [30]. Cardiovascular drugs could also be analyzed [31]. As far as we are concerned, the analysis of corticosteroids in hair has not yet been described.

Many methods have been proposed concerning detection of the corticosteroids in urines. Radioimmunoassay (RIA) is a sensitive method, but as Houghton reports [32], it is not very specific. Gas chromatography–mass spectrometry (GC-MS) is specific and sensitive but difficult to implement since the corticosteroids are slightly volatile and could be denatured with heat. Derivation is possible only for a few corticosteroids [33,34]. High-performance liquid chromatography (HPLC) presents the conditions which are well suited for the separation of these compounds and the use of mass spectrometry for detection provides a good specificity and sensitivity [3,32,35–38]. The present paper describes a method of extraction and identification, starting from the hair, of nine of the principal corticosteroids used in doping (Fig. 1). We used electrospray HPLC-MS to perform these analyses. The method was applied on 19 samples of athletes' hair and the results were compared with the urinalysis of the same athletes.

2. Experimental

2.1. Chemicals and reagents

Cortisone, hydrocortisone, hydrocortisone acetate, prednisone, methylprednisolone, triamcinolone acetonide, corticosterone, betamethasone, dexamethasone, prazepam (IS), β-glucuronidase from *Escherichia coli* (β-glucuronidase type VIII A) were obtained from Sigma (St. Quentin Fallavier, France).

Acetonitrile, formic acid, acetic acid and ammonium formiate of analytical grade were purchased from Carlo Erba (Milan, Italy), methanol and chloroform of HPLC grade were obtained from Prolabo (Paris, France). Ultrapure water was produced with a Purite system (Thames, UK).

2.2. Instrumentation

C_{18}, Si and NH_2 solid-phase extraction (SPE) columns (200 mg/3 ml) from IST are supplied by Touzart and Matignon (Courtabœuf, France). Formiat buffer pH 3 was prepared by dissolving 126 mg of formiate ammonium in 1000 ml of water, and adjusted to pH 3 with pure formic acid.

The ball mill was a model 4200 EI from Kleco (Visalia, CA, USA). Toxitube A from Toxi-Lab (Irvine, CA, USA) are supplied by Amilabo (Chassieu, France). The Vac Elut sample processing station (Analytichem International) was from Prolabo (Paris, France). The LC chain was composed of a binary pump LC 200 from Perkin-Elmer (Les Ulis, France) and an automatic injector Perkin Elmer 200 equipped with an injection loop of 20 μl. The analytical column was a 150×2 mm I.D. Ultrasphère™ UP5ODB C_{18} interchrom, from Interchim (Montluçon, France), 5 μm particle size equipped with a 20 mm guard-column. The mobile phase was acetonitrile and formiate buffer pH 3 at a flow rate of 250 μl/min. The solvent gradient program was as follows: initial acetonitrile was held at 20% for 1

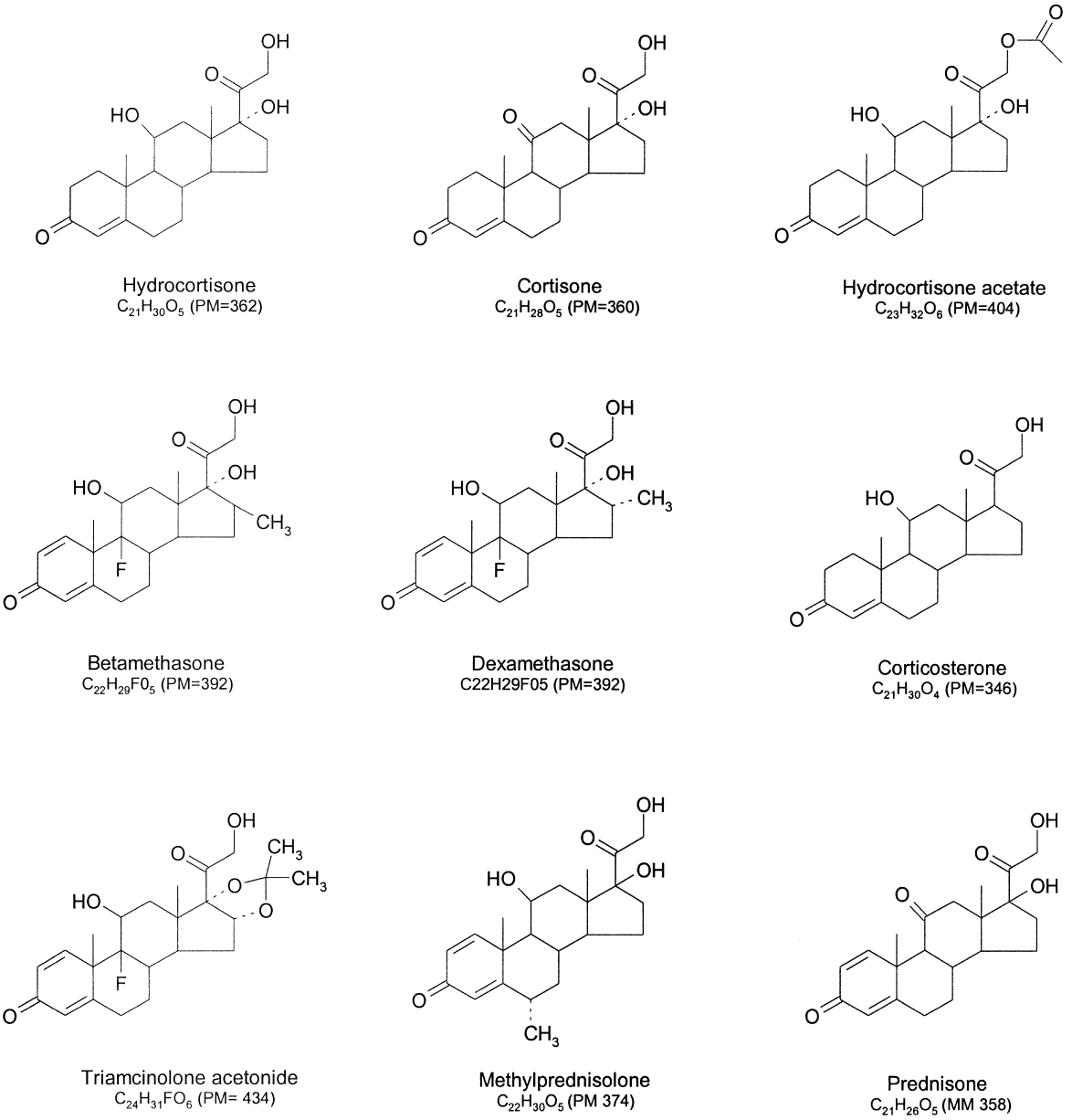

Fig. 1. Chemical structures of corticosteroids.

min, linearly increased to 90% for 19 min, and finally maintained at 90% for 6 min. A split flow (1:3) was applied before entering the ion/source.

Mass detection was carried out on a mass spectrometer API-165 Perkin Elmer-Sciex (Toronto, Canada) equipped with a pneumatically assisted electrospray ionization source. The nebulizer and curtain gas flow/rates were both fixed on 0.8 l/min. The best sensitivity was obtained in negative ionmode despite the chemical structure (3-keto-Δ4 system) makes detection in positive ionmode possible. The main voltage settings of electrospray and MS were optimized for the whole of the corticosteroids study and were as follow: electrospray (IS):

−5000 V; orifice (OR): −80 V; Ring (RNG): −344 V. Regarding prazepam (internal standard) detection was performed in positive ionmode, IS: 5500 V; OR: 92 V; RNG: 360 V. The mass spectrometer was operated in the selected ion monitoring mode. Each sample was analyzed by two successive injections using two detection methods. Table 1 reports analytes and their monitored ions for each detection method.

2.3. Sample collection and preparation

Since 1996, the Society of Hair Testing has proposed a consensus concerning the procedure of hair collection [39]. Hair should be sampled from the vertex posterior at the back region of the scalp. The hair growth rate in this area presents less variability than in the other areas [40].

The blank hair, and those used for the calibration curves, were collected from people not treated with corticosteroids. The hair of 19 athletes were collected during anti-doping control asked for under the authority of the minister of justice (and not under that of the IOC).

The samples were washed by two successive chloroformic baths, 10 min each, by soft agitation. Once dried and finely cut, the hair was processed in a ball mill for 2 min until a fine grey powder was obtained.

2.4. Extraction

2.4.1. Hairs

Fifty milligrams of pulverized hair with 25 ng of IS were incubated with 1 ml of methanol in an ultrasonic bath for 2 h. After centrifugation at 750×*g* for 10 min, the supernatant was transferred to a clean vial and evaporated under a stream of nitrogen at 50°C. The residue was dissolved in 2 ml water and applied on a C_{18} SPE column, first activated with 4 ml of methanol followed by 2 ml water. The column was washed with 1 ml water and dried by passing air through for 20 min in the Vac Elut sample processing station. The analytes were eluted with two volumes of 1 ml methanol. The eluate was evaporated under a stream of nitrogen at 50°C. The dried residue was dissolved in 50 μl of acetonitrile and 20 μl were injected.

2.4.2. Urines

Five milliliters of urine (with 50 ng of IS) were digested with the β-glucuronidase preparation at 56°C for 1 h. Corticosteroids were extracted from digested urines with toxitube A for 10 min by gentle inversion, immediately followed by a centrifugation at 750×*g* for 10 min. The organic phase was transferred to a clean vial and evaporated under a stream of nitrogen at 50°C. The residue was dissolved in 1 ml chloroform and then applied on a Si SPE column, first activated with 2 ml chloroform.

Table 1
Fragment ions and adducts obtained for each compound

Compounds	Molecular weight	Mass fragment ions, *m/z*			
		Base peak	M-H	M-H-30	M-H+46
Cortisone	360.47	329	359	329[a]	405[a]
Hydrocortisone	362.47	331	–	331[a]	407[a]
Corticosterone	346.00	391	–	–	391[a]
Hydrocortisone acetate	404.47	449	403	–	449[a]
Prednisone	358.44	327	357	327[b]	403[b]
Methylprednisolone	374.44	419	373	343[b]	419[b]
Triamcinolone acetonide	434.44	479	–	–	479[b]
Dexa/Betamethasone	392.45	437	391	361[b]	437[b]
IS (Prazepam)	324.81	325[a,b]			

[a] Ions monitored in the first detection method (Cortico 1).
[b] Ions monitored in the second detection method (Cortico 2).

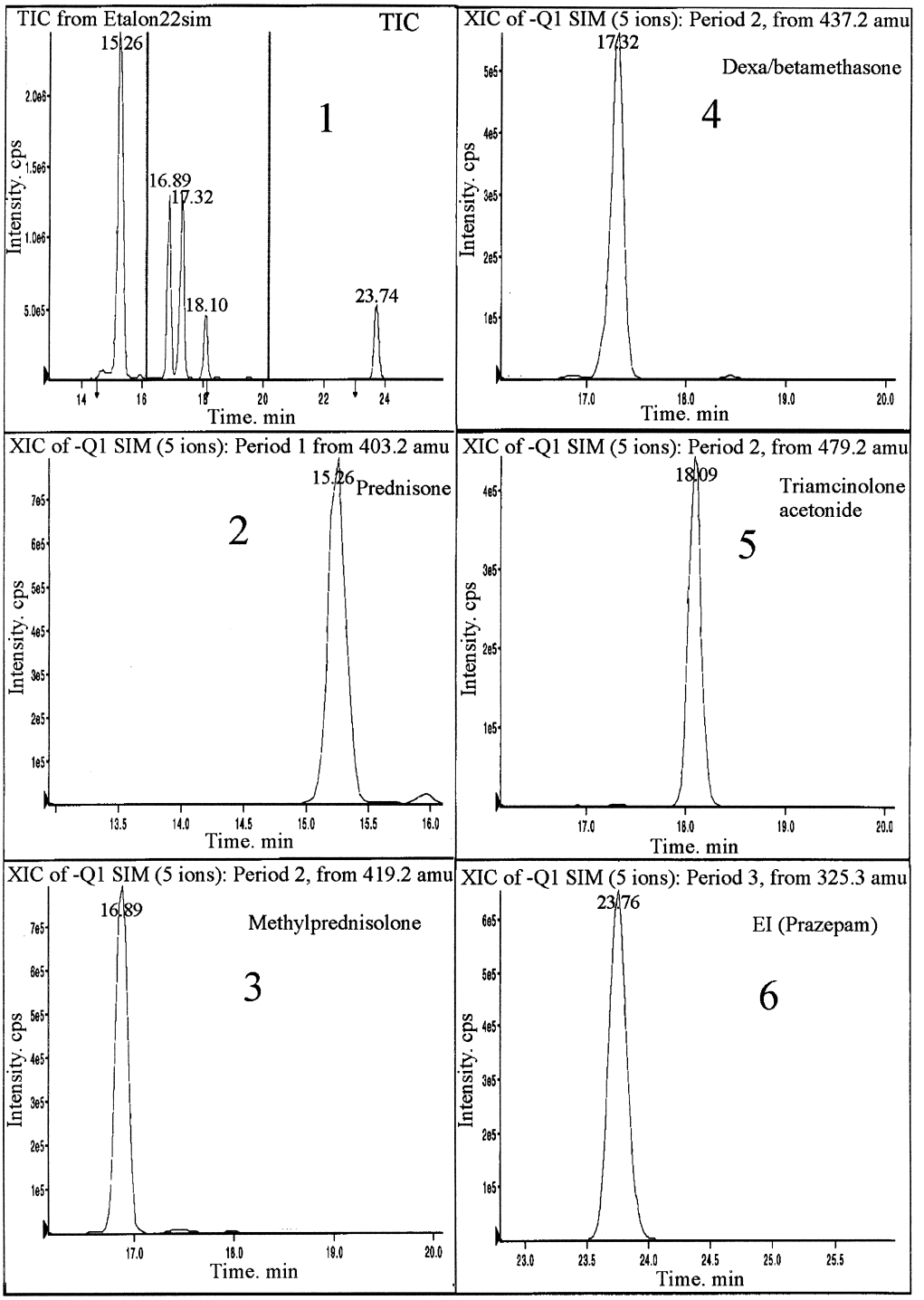

Fig. 2. Total ion chromatogram (1), and extract ion chromatograms of prednisone (2): $m/z=403$, methylprednisolone (3): $m/z=419$, dexa/betamethasone (4): $m/z=437$, triamcinolone acetonide (5): $m/z=479$, EI (6): $m/z=325$.

Analytes were eluted with two volumes of 1 ml methanol. The second solid-phase extraction was performed on a NH_2 SPE column first equilibrated with 2 ml methanol. The eluate, from the first SPE (Si column) was applied directly on this column. The fraction from this deposit was collected directly, and elution was conducted with two volumes of 1 ml 0.2 M acetic acid in methanol. Those fractions and that from the deposit were combined and evaporated under a stream of nitrogen at 50°C. The residue was dissolved in 50 μl acetonitrile and 20 μl were injected.

3. Results

3.1. Hair sample extraction

The solubilization of the substances included in the capillary matrix can be obtained in different ways depending on the physicochemical properties of the analytes. The use of sodium hydroxide or enzymes involves a complete digestion of the hair, whereas the use of acid or organic solvent allows an extraction without dissolution of the hair.

Three techniques were tested in the present study for the corticosteroids extraction: alkaline hydrolysis using sodium hydroxide (70°C for 1 h) was rejected because some corticosteroids are unstable under strong alkaline conditions. The acid hydrolysis (HCl at 50°C for 18 h) and the methanolic extraction allowed a good recovery of the analytes. A study done on hair from a patient treated with prednisone (results not reported here) significantly showed that the signal/noise ratio determined during the assay was higher using the methanolic extraction. This latter method has therefore been chosen.

Table 2
Extraction recoveries and RSD ($n=8$) from hair spiked with 1 ng/mg of each corticosteroid

	Recovery (%)	RSD (%)
Cortisone	78.3	2.5
Hydrocortisone	83.4	4.9
Corticosterone	71.2	4.2
Hydrocortisone acetate	70.6	4.1
Prednisone	85.6	3.9
Methylprednisolone	74.3	1.9
Triamcinolone acetonide	90.2	4.1
Dexa/Betamethasone	71.5	4.7

3.2. SPE optimization

3.2.1. Hair

The hair extract, from the methanolic extraction, was relatively clean. Then SPE on C_{18} cartridge with a single wash step with water was sufficient for this assay procedure.

3.2.2. Urines

The extract from digested urines were not enough purified on C_{18} cartridge since some corticosteroids were eluted very easily, so the wash step (methanol/H_2O; 5/95; v/v) was not sufficient enough. The use of polar sorbent (Si cartridge) gave better results, but some interferences still disturbed the chromatogram. Then we used a second polar sorbent (NH_2 cartridge), by collecting the fraction directly from the deposit. The chromatogram obtained was clean but some analytes had a very low recovery (<30%). The elution with acidic methanol (0.2 M acetic acid in methanol) has increased recoveries without decreasing the chromatogram quality.

3.3. Electrospray HPLC-MS analysis

The total ion chromatogram (TIC) and single ion chromatograms, from a mixture of corticosteroids using the detection method Cortico2 are reported in Fig. 2. The masses of the main ions and adducts of each corticosteroid are gathered in Table 1. Formiate adducts (CH_2O_2), due to the mobile phase, are characterized by peak $[(M-1)^- +46]$. This peak is present for all analytes, and is the base peak of hydrocortisone acetate, corticosterone, prednisolone, triamcinolone acetonide and dexa/betamethasone. The other ion frequently found is $[(M-1)^- -30]$ due to the loss of CH_2O. Dexamethasone and betamethasone were not separated with these chromatographic conditions and presented similar mass spectra under the reported chromatographic method used in this study. This did not create a problem as to the interpretation of the results since the two isomers are subjected to the same restrictions by the IOC. However, Rizea Savu proposed to use a graphite

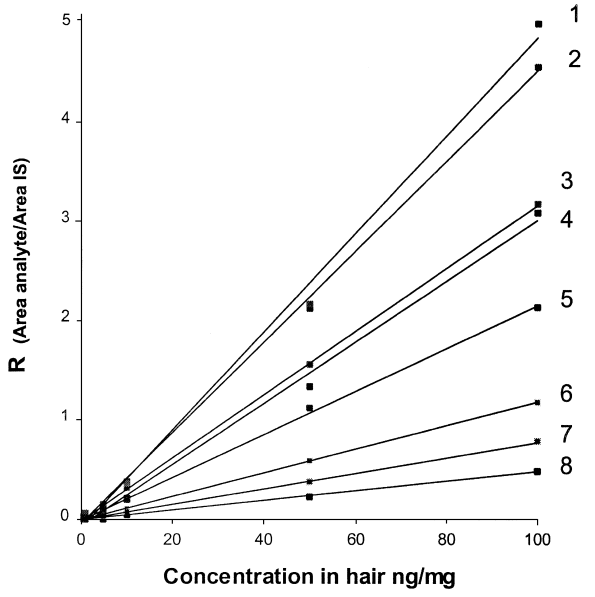

Fig. 3. Calibration curves of: (1) Cortisone (r^2=0.995); (2) Hydrocortisone (r^2=0.999); (3) Triamcinolone acetonide (r^2=0.999); (4) Hydrocortisone acetate (r^2=0.995); (5) Methylprednisolone (r^2=0.997); (6) Dexa/betamethasone (r^2=0.999); (7) Prednisone (r^2=0.999); and (8) Corticosterone (r^2=0.999).

column type Hypercarb Shandon to identify separately these two isomers [35].

For more specificity, two ions were selected for each corticosteroid. Only corticosterone, triamcinolone acetonide, and hydrocortisone acetate were detected by the use of a single ion. Electrospray and detector tensions, optimized for all the corticosteroids, did not allow the formation of two ions of sufficient intensity for these latter compounds.

3.4. Recovery, calibration

Table 2 shows the recoveries and RSD (n=8) following SPE, obtained on hair spiked with 1 ng/mg of each corticosteroid. These recoveries, applied to the detection limits obtained for signal/noise, allow measurements of concentrations higher than 0.1 ng/mg in the hair for the totality of the corticosteroids studied. Calibration curves were built from analysis of extracts of hair blanks spiked with each corticosteroid from 0.1 to 100 ng/mg.

To build those curves, an equation type $y=Ax+B$ were used. The linearity, with all analytes, is good in the whole range of tested concentrations (Fig. 3).

4. Case study

This screening method was used to analyze the hair of nineteen athletes. Results obtained are reported in Table 3. Chromatogram of positive case of dexa/betamethasone is shown in Fig. 4.

From the measured concentrations in hair, it was not yet possible to deduct the exact consumption and thus to determine if the administration corresponds to a therapeutic or supra-therapeutic dose as is often the case in doping. This dose–hair concentration relation, was studied for certain molecules such as cocaine. The results of these studies show that hair analysis does not give a very good quantitative accuracy [41]; however, it makes it possible to evaluate the importance of the exposure [42].

As for synthetic corticosteroids in human doping, concentrations measured in hair are not important

Table 3
Results obtained on athletes' samples n=19

Corticosteroids	Positive hair samples	Positive urines samples
Cortisone	NR[b]	19[a]
Hydrocortisone	NR[b]	19[a]
Corticosterone	0	0
Prednisone	0	0
Hydrocortisone acetate	1 (0.43 ng/mg)	0
Methylprednisolone	1 (1.35 ng/mg)	1 (5.2 ng/ml)
Triamcinolone acetonide	1 (0.28 ng/mg)	5 (2.2–4.8 ng/ml)
Dexa/Betametasone	1 (1.31 ng/mg)	1 (18.4 ng/ml)

[a] Urinary concentrations compatible with physiological values.
[b] NR, not resolved.

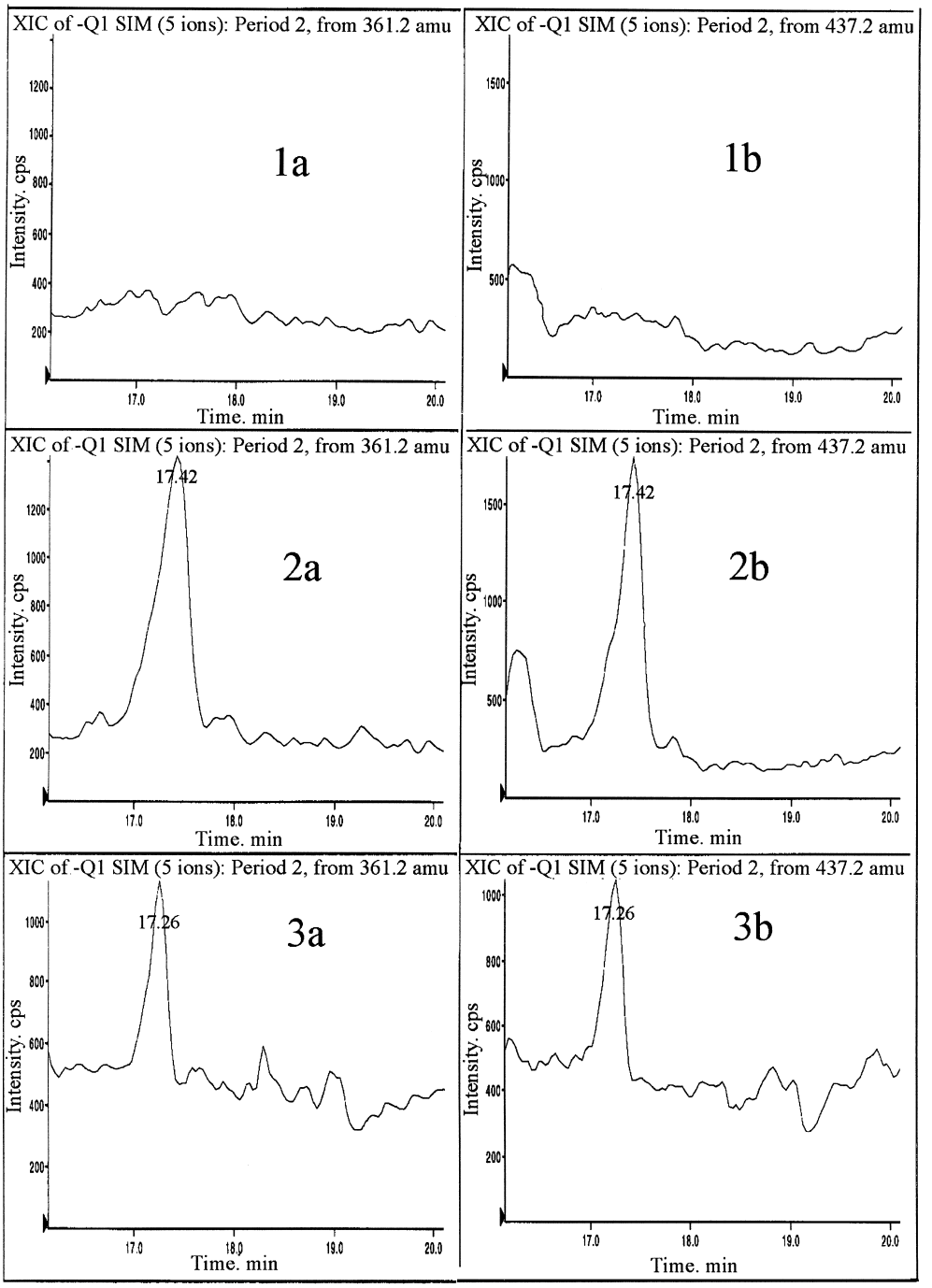

Fig. 4. Extract ion chromatograms (a) $m/z=361$; (b) $m/z=437$) of: blank hair (1); spiked hair with 5 ng/mg dexamethasone (2); and positive hair dexa/betamethasone (3).

since their very presence is considered as a doping case except if it was administered locally or intra-articulary. In both those cases, according to the Sports Federation, the administration has to be declared when the doping control occurs [2], or the administration has to be performed after information by a medical committee [1], not to be considered as a doping case.

5. Comparison urinalysis and hair analysis

Concurrently with hair, urines of the same sportsmen were analyzed by using analytical conditions similar to those used for hair.

The comparison of the results obtained shows once again the dramatic complementarity of urinalysis and hair analysis. Indeed, athletes tested positive for dexa/betamethasone or methylprednisolone in hair whereas urinalysis was negative for these molecules, and tested positive for triamcinolone acetonide in urine whereas hair analysis was negative.

Since the corticosteroids are quickly eliminated, urines only allow the detection of an administration that occurs during the competition subjected to control. Conversely, hair could allow the detection of a doping case during an earlier competition or during the training period which precedes the competition.

Detection of hydrocortisone acetate in hair enables the revelation of a doping case by the use of hydrocortisone acetate. This can not be achieved by urinalysis, since hydrocortisone acetate is eliminated in the form of hydrocortisone and its glucurono and sulfoconjugate metabolites as it was already demonstrated for testosterone esters [29]. Hair analysis could therefore permit the detection of the administration of hydrocortisone if it is given in a pro-drug form. Cortisone and hydrocortisone were not detected in the hair during this study. It could be interesting to extend this work on a wide population by using more significant hair samples to determine if a threshold value could be established.

This threshold value is not yet fixed for urines. Indeed, instantaneous production of corticosteroids is susceptible to many factors (e.g. stress, exercise . . .) and therefore urinary concentrations are difficult to interpret, especially during doping control because it is not possible to analyze a 24 h urine sample.

This is why a study done during the 24th Olympic games showed that some athletes had urinary concentrations of cortisone and hydrocortisone 40 times higher than the average concentration measured on the athletes as a whole [36]. Since there is no efficient legislation concerning these molecules, those athletes could not have been sanctioned. With the difference of the urinalysis, the analysis of hair could make it possible to obtain an average value, and thus a value which could be interpreted, of the natural corticosteroid elimination, this elimination being the reflection of the production and a possible administration of those molecules.

6. Conclusion

We have described a method which allows the simultaneous determination and quantification in the hair of nine of the main corticosteroids used in doping. This method, applied to hair samples collected from athletes during a doping control, makes it possible to highlight positive cases which were not detected in urines. The use of hair in doping controls could then be a complementary investigative tool to urinalysis, because it would increase the detection time window, and reveal doping cases with natural corticosteroids if they are administered as pro-drugs.

References

[1] IOC, List of prohibited classes. January 1997.
[2] Arrêt du 7 octobre 1994 relatif aux substances et aux procédés mentionnés à l'article 1 de la loi 89432 du 28 juin 1989 relative à la répression de l'usage des produits dopants à l'occasion des compétitions et manifestations sportives, J. Off. République Française, 21 Octobre 1994, 14976–14978.
[3] M.A. Popot, P. Garcia, Y. Bonnaire, in: W. Shänger, H. Geyer, A. Gotzmann, U. Mareck-Engelke (Eds.), Proceedings of the 15th Cologne Workshop on Dope Analysis, February 1997, Hansen, Bergish Gladbach, 1998, p. 185.
[4] Y. Nakahara, Forensic Sci. Int. 70 (1995) 135.
[5] P. Kintz, V. Cirimele, A. Tracqui, P. Mangin, J. Chromatogr. B 670 (1995) 162.
[6] P. Kintz, V. Cirimele, Forensic Sci. Int. 84 (1997) 151.
[7] Y. Nakahara, R. Kikura, M. Yasuhara, T. Mukai, Forensic Sci. Int. 84 (1997) 157.

[8] R. Kikura, Y. Nakahara, T. Mieczkowski, F. Tagliaro, Forensic Sci. Int. 84 (1997) 165.
[9] P. Kintz, P. Mangin, Hum. Exp. Toxicol. 11 (1992) 51.
[10] Y. Gaillard, G. Pépin, Forensic Sci. Int. 86 (1995) 49.
[11] S. Balabanova, J. Homoki, Z. Rechstmed. 98 (1987) 235.
[12] E.J. Cone, D. Yousefnejad, W.D. Darwin, T. Maguire, J. Anal. Toxicol. 16 (1991) 250.
[13] S. Balabanova, P.J. Arnold, V. Luckow, H. Brunner, H.U. Wolf, Z. Rechtsmed. 102 (1989) 503.
[14] T. Mieczkowski, Forensic Sci. Int. 70 (1995) 83.
[15] V. Cirimele, P. Kintz, P. Mangin, Forensic Sci. Int. 70 (1995) 175.
[16] Y. Nakahara, R. Kikura, J. Chromatogr. B 700 (1997) 83.
[17] Y. Nakahara, K. Takahashi, T. Sakamoto, A. Tanaka, V.A. Hill, W.A. Baumgartner, J. Anal. Toxicol. 21 (1997) 356.
[18] M.R. Fey, P. Moeller, 43rd Meeting of the American Academy of Forensic Science, Anaheim, CA, February 18–23, 1991.
[19] M.R. Moeller, P. Fey, R. Wennig, Forensic Sci. Int. 63 (1993) 185.
[20] F. Mersh, M. Yegles, R. Wennig, Forensic Sci. Int. 84 (1997) 237.
[21] Y. Gaillard, G. Pépin, J. Chromatogr. B 709 (1998) 69.
[22] A. Tracqui, P. Kintz, P. Mangin, Forensic Sci. Int. 42 (1997) 111.
[23] H. Sachs, M. Uhl, G. Hege-Scheuing, E. Schneider, Int. J. Legal Med. 109 (1996) 213.
[24] P. Kintz, P. Mangin, Arch. Toxicol. 68 (1994) 210.
[25] G. Skopp, K. Kindler, L. Potsch, G. Zimmer, R. Lutz, R. Aderjan, R. Mattern, Forensic Sci. Int. 95 (1998) 99.
[26] P. Kintz, V. Cirimele, Y. Edel, A. Traqui, P. Mangin, Int. J. Legal Med. 107 (1995) 269.
[27] Y. Gaillard, A. Balland, F. Doucet, G. Pépin, J. Chromatogr. B 703 (1997) 85.
[28] K.M. Höld, D.G. Wilkins, D.J. Crouch, D.E. Rollins, R.A. Maes, J. Anal. Toxicol. 20 (1996) 345.
[29] Y. Gaillard, F. Vayssette, A. Balland, G. Pépin, J. Chromatogr. B 735 (1999) 189–205.
[30] Y. Gaillard, G. Pépin, Forensic Sci. Int. 43 (1998) 235.
[31] P. Kintz, P. Mangin, Eur. J. Clin. Pharmacol. 42 (1992) 351.
[32] E. Houghton, M.C. Dumasia, J.K. Wellby, Biomed. Mass Spectrom. 8 (1981) 558.
[33] P. Delahaut, P. Jacquemin, Y. Colemonts, M. Dubois, J. De Graeve, H. Deluyker, J. Chromatogr. B Biomed. Sci. Appl. 696 (1997) 203.
[34] S.M.R. Stanley, B.S. Wilhelmi, J.P. Rodgers, J. Chromatogr. 620 (1993) 250.
[35] S. Rizea Savu, L. Sivestro, A. Haag, F. Sörgel, J. Mass Spectrom. 31 (1996) 1351.
[36] S.J. Park, Y.J. Kim, H.S. Pyo, J. Park, J. Anal. Toxicol. 14 (1990) 102.
[37] Y. Kim, T. Kim, W. Lee, Rapid. Commun. Mass. Spectrom. 11 (1997) 863.
[38] D.S. Skrabalak, K.K. Cuddy, J.D. Henion, J. Chromatogr. 341 (1985) 261.
[39] Society of Hair Testing, Forensic Sci. Int. 84 (1997) 3.
[40] M.R. Harkley, Forensic Sci. Int. 63 (1993) 9.
[41] G.L. Henderson, M.R. Harkley, C. Zhou, R.T. Jones, P. Jacob, J. Anal. Toxicol. 20 (1996) 1.
[42] G. Pepin, Y. Gaillard, Toxicorama 8 (1996) 29.