IDENTIFICATION OF XENOBIOTIC METABOLITES IN COMPLEX BIOLOGICAL MATRICES USING ADVANCED HIGH RESOLUTION UPLC/MS ACQUISITION TECHNIQUES AND MULTIVARIATE STATISTICAL METHODS

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Introduction

Multivariate statistical methods have typically been used in metabonomic/metabolomic studies to study endogenous metabolite patterns and how they are altered after some perturbation of a biological system. In this work we present a method for identification of xenobiotic metabolites in a complex biological matrix using advanced statistical methods and exact mass data filters.

High resolution UPLC/MS data for control and dosed animals is acquired using elevated energy acquisition (MS^E). This technique provides both the low energy data set with parent masses and a high energy data set with daughter ion information. The low energy data set is fist processed using an exact mass data filter to remove much of the endogenous background. Exact mass data filters exploit the mass sufficiency/deficiency of the parent drug and its potential metabolites and are one of the major advantages of acquiring data with accurate mass measurement. The resulting filtered data is then analyzed by orthogonal projection on latent structure (OPLS). OPLS is a modification of the common partial least squares method which allows filtering of confounding variations from the analysis resulting in an easier to interpret dataset. This enhances our ability to detect potential metabolites (differences between control and dosed samples related to the parent drug) which might not be easily predicted.

The potential metabolites are assigned tentative structures and these tentative assignments are confirmed using the daughter ion information from the high energy data set. An automated fragmentation tool allows rapid confirmation of the proposed biotransformation and can localize the site of biotransformation to a high level of confidence.

Methods

LC/MS Methodology:

Mass Spectrometer: **Q-Tof Premier™**

MS scan range: 70-900 Da
Mode of Operation: +/-ve ion mode ESI
V-mode, pDRE (dynamic range enhancement)
Lock Mass: Leucine Enkephalin at 200 pg/mL

MS^E Methodology:

The Q-Tof Premier was operated in a parallel data acquisition mode with a wide band RF mode in Q1 (Figure 1). Thus, allowing all ions in the collision cell. This resulted in one single injection in which data was collected under one single data file with two functions. These were;

Function 1) Low energy acquisition (5eV) which contained the unfragmented compounds

Function 2) High energy or MS^E acquisition (15eV-30eV ramp) which contained all of the fragmented ions

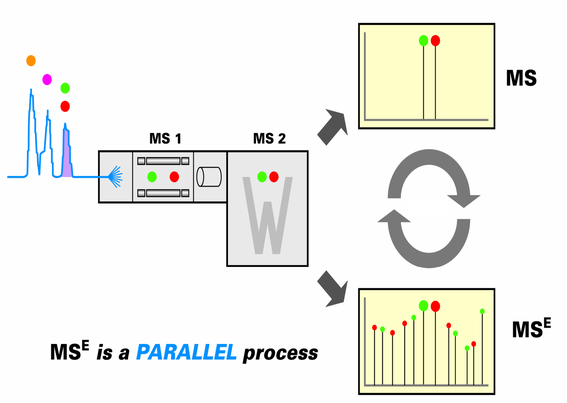

Figure 1. MS^E data acquisition

UPLC conditions:

ACQUITY UPLC™

ACQUITY UPLC BEH C18 Column
100 x 2.1 mm id, 1.7 µm

Mobile phase A: 0.1 % formic acid
Mobile phase B: Acetonitrile
Flow rate: 0.6 mL/min
Gradient: 0 min 98% A,
0-10 min 20% A,
Typical chromatograms shown in Figures 2 and 3.
10-11 min 0% A

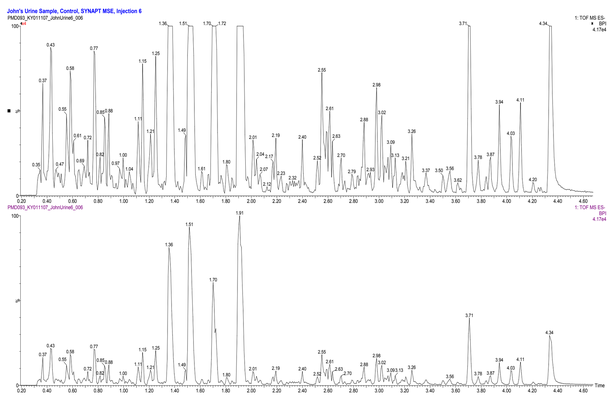

Figure 2. BPI Chromatogram for control urine samples.

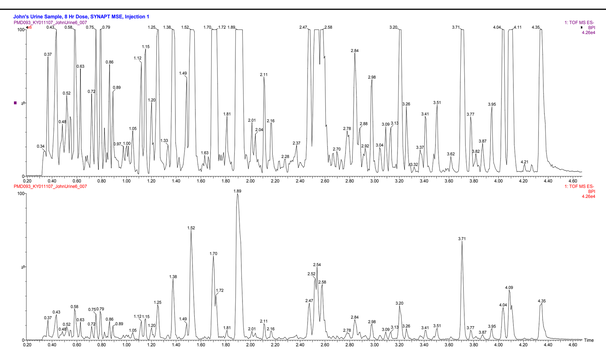

Figure 3. BPI Chromatogram for dosed urine samples.

Dosing:

Human volunteers were given a single 400 mg dose of ibuprofen prior to sleep. Urine samples were obtained 8 hours after dosing. The control samples were obtained from each volunteer just prior to dosing.

DATA EXTRACTION AND EXACT MASS DATA FILTERS

The data from an LC/MS or GC/MS analysis must be in a tabular format before it can be mined using multivariate statistics. This is accomplished using the **MarkerLynx™** Application Manager. MarkerLynx will process the samples and create a data matrix with all exact mass, retention time pairs (EMRT's) observed in all the samples and the measured area from their XICs listed (see Figure 4).

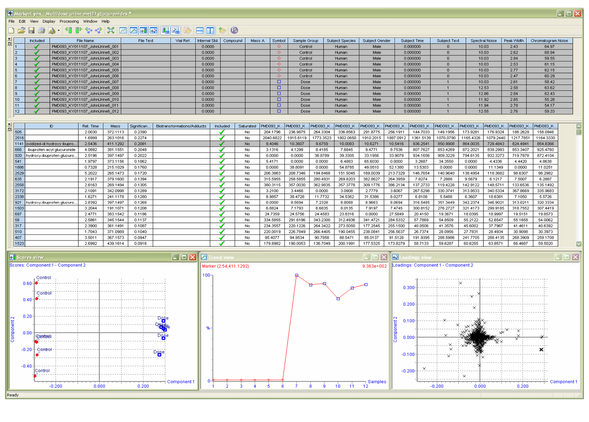

Figure 4. Data extraction with MarkerLynx™ and basic Multivariate Data Analysis (MVA).

Since we are interested in only those EMRT pairs which are parent drug related we can apply an exact mass data filter to remove a significant amount of the chemical background from our matrix. Exact mass data filters use the decimal portion of the parent mass, in the case of ibuprofen m/z 205.1234, we are concerned with only 0.1234. If we hydroxylate ibuprofen we add oxygen which would change the fractional portion of the m/z to 0.1184 which is a decrease of 5.1 mDa. This decrease will be the same for the mono-hydroxylation of any compound. So it is possible for us to create a hydroxylation filter which would reject any m/z with decimal values which are not 5.1 mDa below our parent compound, the result being the elimination of chemical noise from our analysis. In practice we would set a window to include the parent and other common metabolic transformations using our knowledge of the decimal portion of these transformations as a guide (see Table 1).

Elemental Composition	Mass shift		Δ values for calculation of exact mass data filters
	Nominal mass	Accurate mass	
+O	+16	+ 15.9949	- 0.0051
+O2	+32	+ 31.9898	- 0.0102
-H2	-2	- 2.0157	- 0.0157
-CH2	-14	- 14.0157	- 0.0157
-Cl+O	-18	- 17.9662	+0.0338
+C2H2O	+42	+ 42.0106	+0.0106
+SO3	+80	+ 79.9568	- 0.0432
+C6H8O6	+176	+176.0321	+0.0321
+C6H8O 7	+192	+192.0270	+0.0270
+C2H5NO2S	+107	+107.0042	+0.0042
+C10H15N3O6S	+305	+305.0682	+0.0682

Table 1. *Some common biotransformation and their associated Δ values for calculation of exact mass data filters.*

Basic Multivariate Data Analysis

Multivariate Data Analysis (MVA) extracts the information from large data sets and presents the results as interpretable plots based on the mathematical principle of projection. Even data characterized by thousands of variables can be reduced to just a few information rich plots. Basically we are separating signal from noise in data with many variables and presenting the results in a graphical format. Any large complex table of data can be easily transformed into intuitive plots summarizing the essential information. The First step in analyzing samples from a xenobiotic metabolism study is to determine if the data show a difference between the control and dosed groups. This was accomplished by examination of the scores plot, created using **SIMCA-P** version 11.5 from **Umetrics**, shown in Figure 5. Here we can clearly see that the dose samples are, as we would expect, different from the control.

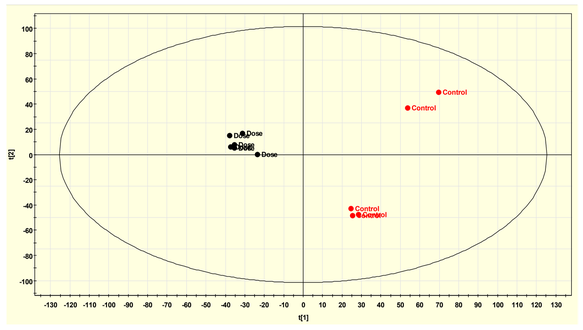

Figure 5. PCA scores Plot, showing dose and control groups.

The second step is to examine the loadings plot (Figure 6) and from it determine which compounds, described as EMRT pairs, which are responsible for the difference between the dosed animals and the controls. The EMRT pairs which are the most significant in separating the groups, are those furthest from the origin of the loading plot. Ibuprofen and/or its metabolites will be among these. Using this approach we can extract our signal from the chemical noise in the samples.

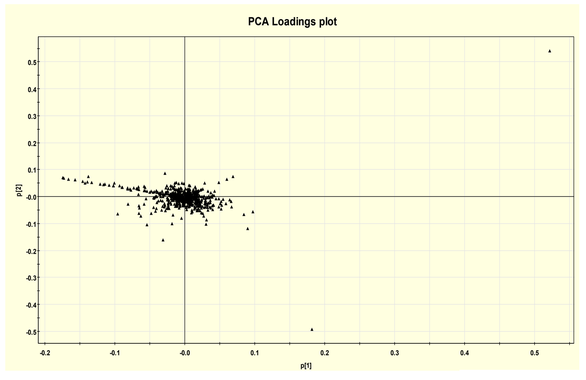

Figure 6. PCA Loadings plot.

ADVANCED STATISTICAL METHODS

One of the problems with this approach is that often the loading plot is difficult to interpret and it does not provide us with information about the confidence limits of our measurements. Orthogonal projection on latent structure (OPLS) is a novel new technique which allows us to compare two groups and orthogonalizes the results such that the variance between the groups is aligned with the x- axis (Figure 7) and loading can be more easily interpreted.

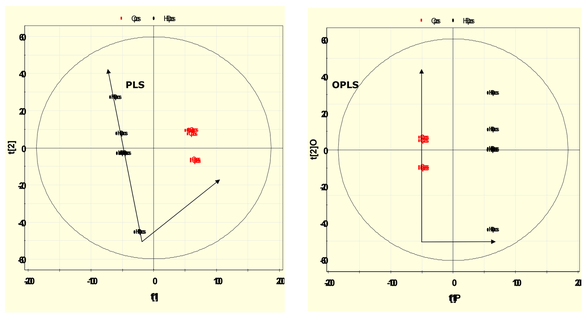

Figure 7. PLS plot compared to an OPLS plot showing the effect of orthogonalization.

If we plot the weight of the variable along the x-axis against a parameter which describes the analytical reliability of the loading we obtain the S-Plot. The S-Plot is superior to the normal loadings scatter plot because of its two dimensional nature. It allows us to easily extract even subtle differences in data sets and provides an easy way to visualize both weight and reliability of the measured variables (Figure 8 and 9).

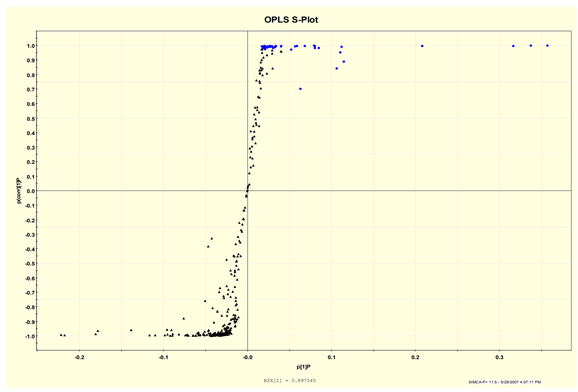

Figure 8. S-Plot from the OPLS analysis.

The S-Plot is very easily interpreted. The further along the x-axis from the origin the larger the contribution to the variance between the groups (covariance). The further along the y-axis from the origin the higher the reliability of the data (correlation). Thus the *blue dots* in the upper right quadrant are those *EMRT pairs* which are high in the dosed sample and potential metabolites of Ibuprofen .

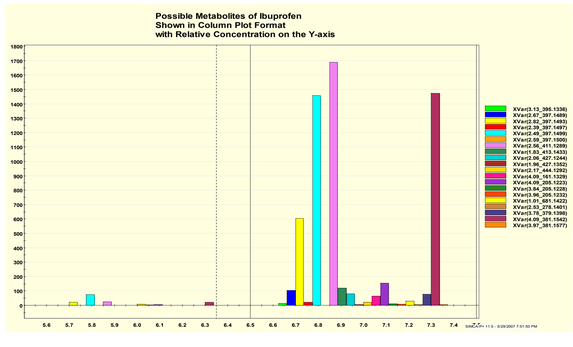

Figure 9. Possible metabolites of Ibuprofen and their relative concentrations.

TENTATIVE IDENTIFICATION OF METABOLITES

Taking the list of potential metabolite EMRT's back to MarkerLynx and searching against a database of known and proposed ibuprofen metabolites we can quickly identify the biotransformations that may have occurred (Table 2).

	ID	Ret. Time	Mass ↑	Formula	Database	SIMCA1	SIMCA2
1	oxidized-tetra-hydroxy ibuprofen glucuronide	2.1445	443.1352	C19H24O12	ibuprofen (ChemFcider)	0.0237	0.9953
2	oxidized-tri-hydroxy ibuprofen glucuronide	1.9647	427.1352	C19H24O11	ibuprofen (ChemFcider)	0.0186	0.9827
3	oxidized-tri-hydroxy ibuprofen glucuronide	2.0577	427.1244	C19H24O11	ibuprofen (ChemFcider)	0.0786	0.9997
4	di-hydroxy-ibuprofen glucuronide	1.8342	413.1433	C19H26O10	ibuprofen (ChemFcider)	0.0845	0.9843
5	oxidized-di hydroxy ibuprofen glucuronide	2.5553	411.1289	C19H24O10	ibuprofen (ChemFcider)	0.3563	0.9996
6	hydroxy-ibuprofen glucuronide	2.4949	397.1499	C19H26O9	ibuprofen (ChemFcider)	0.3157	0.9966
7	hydroxy-ibuprofen glucuronide	2.3861	397.1497	C19H26O9	ibuprofen (ChemFcider)	0.0397	0.9971
8	hydroxy-ibuprofen glucuronide	2.8239	397.1493	C19H26O9	ibuprofen (ChemFcider)	0.2076	0.9990
9	oxidized-mono-hydroxy ibuprofen glucuronide	3.1313	395.1336	C19H24O9	ibuprofen (ChemFcider)	0.0305	0.9843
10	oxidized-mono-hydroxy ibuprofen glucuronide	3.0704	395.1330	C19H24O9	ibuprofen (ChemFcider)	0.0225	0.9759
11	ibuprofen acyl glucuronide	3.9652	381.1577	C19H26O8	ibuprofen (ChemFcider)	0.0170	0.9955
12	ibuprofen acyl glucuronide	4.0935	381.1542	C19H26O8	ibuprofen (ChemFcider)	0.3369	0.9993
13	oxidized-tetrahydroxy-ibuprofen	2.4393	267.1346	C13H18O6	ibuprofen (ChemFcider)	0.0274	0.9921
14	ibuprofen	3.9562	205.1232	C13H18O2	ibuprofen (ChemFcider)	0.0262	0.9988
15	ibuprofen	3.8377	205.1228	C13H18O2	ibuprofen (ChemFcider)	0.0275	0.9986
16	ibuprofen	4.0943	205.1223	C13H18O2	ibuprofen (ChemFcider)	0.1117	0.9912

Table 2. Proposed metabolites of Ibuprofen.

If we desire to examine the effect of dosing ibuprofen on endogenous metabolism we need only highlight and exclude the EMRT pairs from our table and repeat the statistical analysis. However, this approach is also an effective way to conduct a xenobiotic metabolism study. From our list of metabolites in Table 2 we propose the structures shown Table 3.

#List	#	#ID	Structure	Name	Formula	Monoisotopic...
	1	1		ibuprofen	$C_{13}H_{18}O_2$	206.13068 Da
	2	9		ibuprofen acyl glucuronide	$C_{19}H_{26}O_8$	382.162768 Da
	3	10		tetra-hydroxy-ibuprofen glucuronide	$C_{19}H_{26}O_{12}$	446.142426 Da
	4	11		tri-hydroxy-ibuprofen glucuronide	$C_{19}H_{26}O_{11}$	430.147512 Da
	5	12		di-hydroxy-ibuprofen glucuronide	$C_{19}H_{26}O_{10}$	414.152597 Da
	6	13		hydroxy-ibuprofen glucuronide	$C_{19}H_{26}O_9$	398.157682 Da
	7	14		oxidized-di hydroxy ibuprofen glucuronide	$C_{19}H_{24}O_{10}$	412.136947 Da
	8	15		oxidized-tri-hydroxy ibuprofen glucuronide	$C_{19}H_{24}O_{11}$	428.131862 Da
	9	16		oxidized-tetra-hydroxy ibuprofen glucuronide	$C_{19}H_{24}O_{12}$	444.126776 Da
	10	17		oxidized-mono-hydroxy ibuprofen glucuronide	$C_{19}H_{24}O_9$	396.142032 Da

Table 3. Structures of proposed metabolites of Ibuprofen.

CONFIRMATION OF STRUCTURE USING MassFragment™ SOFTWARE

A novel algorithm[1] was used for the structure elucidation step. From the high energy acquisition the metabolite structure was confirmed by using the fragment ions generated. Therefore, MassFragment was used to elucidate the structure of the metabolites. MassFragment is not a rule-based approach but consists on systematic bond disconnections which by the use of exact mass in combination with the probability of breaking certain bonds it provides a reliable and easy strategy to elucidate putative metabolites. From Figure 10, it can be observed the proposed structure for the oxidized di-hydroxy ibuprofen glucuronide metabolite at m/z 411.1289

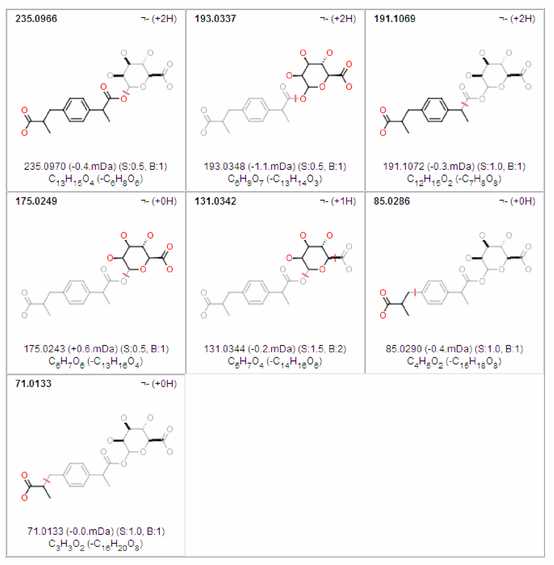

Figure 10. Proposed Oxidized di-hydroxy ibuprofen glucuronide metabolite high energy spectra processed with MassFragment

CONCLUSIONS

The ability to mine a complex matrix like urine and generate a list of 40 to 50 EMRT pairs, with no user bias, and then from that list further mine for potential metabolites using a combination of analytical tools, like neutral losses and common fragment ions along with knowledge of metabolism, comprises a practical and effective approach to identify and/or remove xenobiotic metabolites in a metabolomic study.

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References : [1]*Mortishire-Smith et.al. Rapid Commun. Mass Spectrom. 2005; 19: 3111–3118*

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