

Note d'application

## Drug Metabolite Identification Using Waters™ SELECT SERIES™ Cyclic™ Ion Mobility Mass Spectrometer and waters\_connect™ Application Manager

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### Abstract

We describe the use of ion mobility-enabled high-resolution mass spectrometry in combination with powerful informatics tools to characterize the *in vivo* metabolic fate of fasiglifam, a drug withdrawn from clinical trials after it demonstrated the potential to cause liver damage. A total of 15 drug-related metabolites were detected across the time course with an average  $m/z$  error of  $-0.77$  ppm. The precursor, product ion, and collision cross section data allowed a localization of the site of biotransformation in most cases.

### Benefits

- Robust generic data acquisition strategy which enables rapid analysis
  - Simple and customizable workflow, which can be tailored to meet user needs
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- Tools to facilitate confident metabolite identification

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## Introduction

Metabolite identification, and subsequent profiling, plays a key role in the drug discovery and development processes. It provides critical information for lead candidate selection pharmacokinetics optimization in early discovery, support of safety assessment studies, and ensuring safety in clinical trials. Drug metabolism scientists must resolve the tension between the need for timely turnaround of results and the requirement that outcomes are generated with sufficient confidence and accuracy. In drug discovery, where the number of new compound entities needing analysis is high, there is need for a higher throughput and relatively generic approach which can be streamlined and used across a variety of compound classes without the need to tailor the methodology for each compound under investigation. In the discovery stage, relatively little is known about the metabolic fate of the molecule and so detection/identification must be performed using the mass spectral characteristics of the compound under investigation, and the likely routes of metabolism for the relevant chemotype.

In contrast, in drug development comprehensive metabolite detection/identification is more important than throughput, thus there is a need for expert systems that allow strong data mining and structural elucidation tools. There may be previous knowledge of the metabolism of the compound from *in vitro* studies or early animal studies. Under these circumstances, a combination of targeting known metabolites and characterizing novel metabolites are applied to fully characterize the fate of the molecule for the regulatory package.

Thus, there is a need for an integrated, automated acquisition, and processing system for drug metabolite detection, mining, and identification. Here, we describe the combination of ion mobility-enabled high-resolution liquid chromatography (LC-MS) with an intelligent, data-driven, structural assignment workflow.

Ion mobility MS, using the Waters SELECT SERIES Cyclic IMS combined with the rapid high-resolution chromatography provided by ACQUITY™ UPLC™ offers a powerful flexible platform for both discovery and development metabolite identification when combined with the Metabolite Identification Application Solution with UNIFI™ via waters\_connect. Here, we illustrate the benefit of this solution for the identification of the *in vivo* metabolites of fasiglifam (TAK875) Figure 1, a GPR40 agonist withdrawn from phase III trials due to after the observation of elevated liver enzymes.<sup>1</sup>

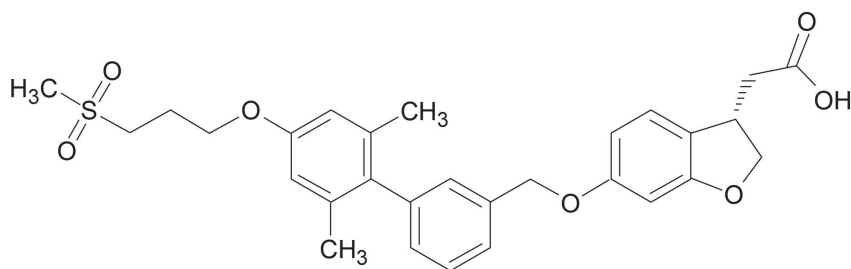


Figure 1. Structure of fasiglifam (TAK875).

## Experimental

### Sample Description

Male Sprague-Dawley rats were dosed orally with 50 mg/kg fasiglifam as a suspension in 0.5% carboxymethylcellulose in water. Blood was collected from the tail vein immediately prior to dosing and at regular intervals over the following 96 hours. Plasma obtained from blood samples was subjected to protein precipitation *via* mixing with acetonitrile at a ratio of 3:1 (acetonitrile:sample). Following vortex mixing the samples were centrifuged at 13,000 RCF for 10 minutes and transferred to an autosampler vial for analysis. Authentic fasiglifam standard was dissolved in methanol and diluted with 50:50 acetonitrile:water to give a final drug concentration of 100 ng/mL. This sample was used to obtain representative retention time, mass spectrometry (MS), tandem mass spectrometry (MS/MS), collision cross section (CCS), and neutral loss outcomes for the parent compound.

### Method Conditions

The authentic standard and extracted rat plasma samples were analyzed using reversed-phase liquid chromatography coupled with negative ion electrospray ion mobility mass spectrometry detection. Briefly, a 1  $\mu$ L aliquot of the sample was loaded onto a 2.1 x 100 mm ACQUITY™ HSS T3 1.8  $\mu$ m C<sub>18</sub> Column, the column was maintained at 40 °C and eluted with a linear solvent gradient of 40–70% 0.1% aqueous formic acid:acetonitrile over ten minutes at a flow rate of 500  $\mu$ L/min. Mass spectrometry data was collected in negative ion mode over the range of 50–1200 *m/z*, using a collision energy ramp of 20–40 eV and a single pass of the ion mobility cell.

## LC Conditions

|                   |  |
|-------------------|--|
| LC system:        | ACQUITY UPLC I-Class   |
| Detection:        | ESI- MS  |
| Vials:            | Max Recovery Vials   |
| Column(s):        | ACQUITY HSS T3 2.1 x 100, 1.8 $\mu$ m                            |
| Column temp.:     | 40 °C  |
| Sample temp.:     | 10 °C  |
| Injection volume: | 1 $\mu$ L  |
| Flow rate:        | 500 $\mu$ L/min  |
| Mobile phase A:   | 0.1% aqueous formic acid   |
| Mobile phase B:   | Acetonitrile containing 0.1% formic acid                         |
| Gradient:         | Chromatographic gradient conditions are given in the table below |

## Gradient Table

| Time (min) | Flow (mL/min) | %A | %B | Curve |
|------------|---------------|----|----|-------|
| 0          | 0.5           | 60 | 40 | 6     |
| 0.5        | 0.5           | 60 | 40 | 6     |
| 10         | 0.5           | 30 | 70 | 6     |
| 10.1       | 0.5           | 5  | 95 | 6     |
| 12         | 0.5           | 5  | 95 | 6     |
| 12.1       | 0.5           | 60 | 40 | 6     |

## MS Conditions

MS system: Waters SELECT SERIES Cyclic IMS

Ionization mode: Electrospray Negative Ion

Acquisition range: 60–1200  $m/z$ , HDMS<sup>E</sup>

Capillary voltage: 2 kV

Collision energy: Transfer cell ramp: 20–40 eV

Cone voltage: 30 V

## Data Management

Chromatography software: MassLynx™ 4.2

MS software: MassLynx 4.2

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## Results and Discussion

### Metabolite Identification Workflow

The process of drug metabolite identification involves the development of a data acquisition methodology, acquisition of the data, componentization of the raw data, component review and finally reporting. For drug discovery applications in particular, generic strategies are preferred in order to drive throughput, and to this end the HDMS<sup>E</sup> mode of data acquisition is ideal, since it affords precursor, product ion, and CCS outcomes in one simple method. To streamline the data acquisition and analysis process we have developed a simple workflow which combines the analyte characterization capabilities of the Waters SELECT SERIES Cyclic Ion Mobility Mass Spectrometer with the data analysis power of the waters\_connect Metabolite Identification Application Solution. The workflow is described in Figure 2 and is divided into 4 simple steps: 1) creation of the analysis method, 2) library entry creation for the parent and known metabolites, and chemically intelligent targeting of unknown metabolites, 3) data filtering and review, and 4) data visualization and reporting.

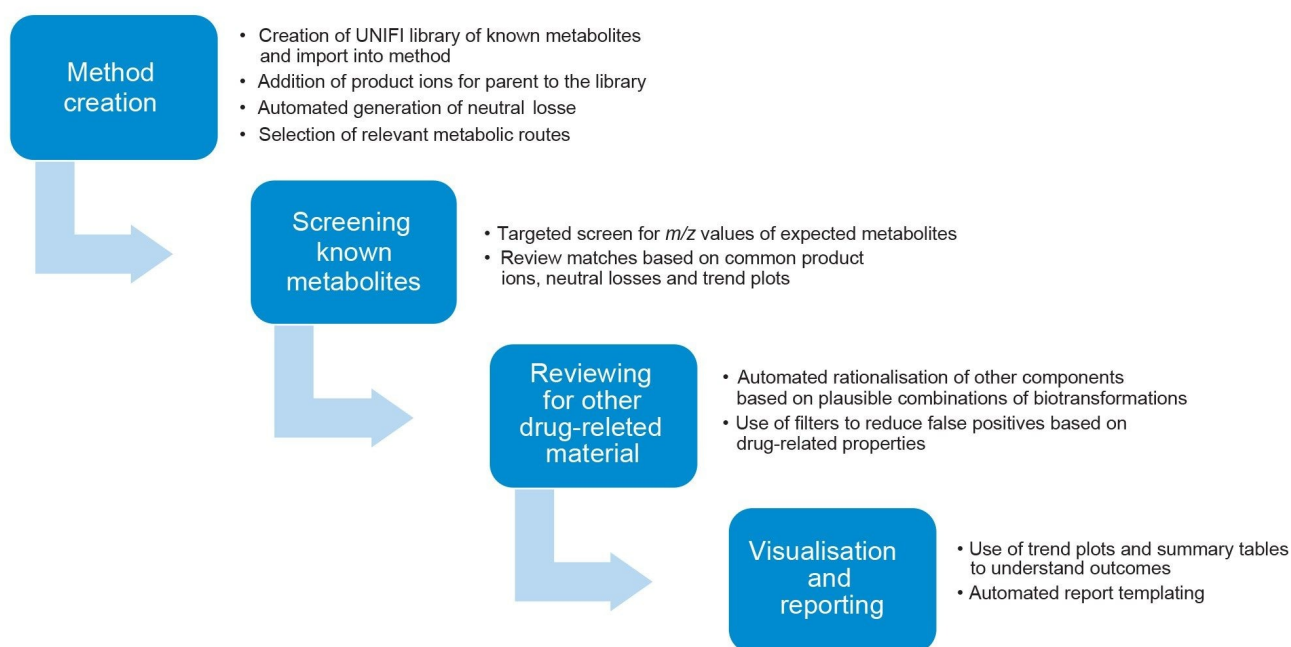


Figure 2. waters\_connect Metabolite Identification Workflow.

## Libraries of Known Metabolites and Generation of Putative Metabolites

Drug metabolism is performed at various stages of the drug discovery and development process, starting in the initial stages when little is known about the metabolic fate of a compound, too late in clinical development when the compound has been extensively characterized both *in vitro* and *in vivo*. The waters\_connect Metabolite Identification application enables targeting of known metabolites via the construction of library entries (Figure 3). Here, the structures of known metabolites, together with that of the parent drug, are added to a library which is then used to interrogate the LC-MS data. If available, previously established retention time, product ion and CCS values can be added to the library and included in the screening method. For example, the experimentally observed product ions of fasiglifam have been added to the method, as have the corresponding neutral losses. Along with these known drug metabolites, the data can be examined for novel metabolites using a combination of the structure of the parent compound, and common metabolic functionalization reactions, including both Phase 1 and Phase 2 (Figure 4). The user has the option to determine which target metabolite can be further functionalized via the 'Generate Transformations' checkbox. Once the appropriate list of targets has been created, the acquired LC-IM-MS raw data can be processed to detect and identify drug-related material.

| Manage Components  |                |               |  |         |                                     |             |                   |
|--|----------------|---------------|--|---------|-------------------------------------|-------------|-------------------|
| Create Import Paste Results Delete Edit Fragments... Edit Adducts... Add To Common Fragments Add To Neutral Losses |                |               |  |         |                                     |             |                   |
|  | Component name | Expected n... | Expected fragment (m/z)  | Adducts | Generate transformations            | Formula     | Expected RT (min) |
| 1  | tak875         | 524.1869      | 479.1898, 359.1653, 148.0530, 403.1551, 192.0428, 439.1585, 463.1585, 385.1445, 147.0452, 133.0295 | -H      | <input checked="" type="checkbox"/> | C29H32O7S   |                   |
| 2  | tak875 M-I-G   | 538.1509      |  |         | <input type="checkbox"/>            | C25H30O11S  |                   |
| 3  | tak875-G       | 700.2190      |  |         | <input type="checkbox"/>            | C35H40O13S  |                   |
| 4  | tak875-tau     | 631.1910      |  |         | <input type="checkbox"/>            | C31H37NO9S2 |                   |
| 5  | tak875 M-I     | 362.1188      |  |         | <input type="checkbox"/>            | C19H22O5S   |                   |
| 6  | tak875 M-II    | 194.0579      |  |         | <input type="checkbox"/>            | C10H10O4    |                   |
| 7  | T-1676427      | 540.1818      |  |         | <input type="checkbox"/>            | C29H32O8S   |                   |

Figure 3. Library of known metabolites used for targeted analysis of data.

| Selected transformations |                              |                 |           |            |                                     |
|--------------------------|------------------------------|-----------------|-----------|------------|-------------------------------------|
|                          | Name                         | Delta Mass (Da) | Formula   | Classifier | Is combined                         |
| 1                        | Desaturation                 | -2.0157         | -H2       | Phase I    | <input type="checkbox"/>            |
| 2                        | Oxidation + desaturation     | 13.9793         | +O-H2     | Phase I    | <input type="checkbox"/>            |
| 3                        | Hydration                    | 18.0106         | +H2O      | Phase I    | <input type="checkbox"/>            |
| 4                        | 2 x Oxidation + Desaturation | 29.9742         | -H2+O2    | Phase I    | <input type="checkbox"/>            |
| 5                        | 2 x Oxidation                | 31.9898         | +O2       | Phase I    | <input checked="" type="checkbox"/> |
| 6                        | Dihydrodiol formation        | 34.0055         | +H2O2     | Phase I    | <input type="checkbox"/>            |
| 7                        | Sulfation                    | 79.9568         | +SO3      | Phase II   | <input type="checkbox"/>            |
| 8                        | Carnitine conjugation        | 144.1025        | +C7H14O2N | Phase II   | <input type="checkbox"/>            |
| 9                        | Glycine conjugation          | 57.0215         | +C2H3NO   | Phase II   | <input type="checkbox"/>            |

Maximum number of transformations:

Phase I:

Phase II:

☐ Filter transformation list based on functional groups that are present

☒ Run the cleavage tool

☒ Allow heterocyclic ring cleavages

Minimum mass cutoff:  Da

Figure 4. Generation of putative drug metabolites using chemical intelligence.

## Identification of Drug-Related Material

One of the significant challenges which exists in metabolite characterization is the identification of drug-related material in the presence of complex endogenous matrix interference. A powerful approach which allows the user to minimize wasted time is the use of custom filters which, when applied in a workflow step, select only those compounds which have a high likelihood of being significant. These can be generalized (having a response



greater than a defined level, being within a retention time which excludes the injection front and high organic wash periods), or compound-specific (have a plausible explanation, contain halogens, have a product ion or neutral loss in common with the parent compound, or are within the allowed mass defect region) (Figure 5).

#### Enter the filter criteria

**Match all of these expressions**

- Identification status is Identified
- Observed RT (min) is between 2.0 : 8 min
- Response is greater than 400
- Within Mass Defect Region is Yes

**Match any of these expressions**

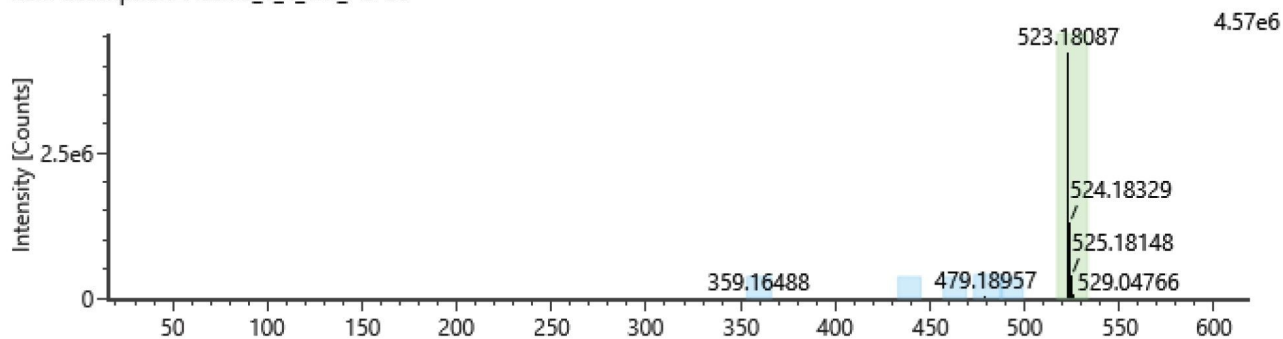
- Expected Fragments Found is greater than or equal 1
- Has Common Fragment Ions is Yes
- Has Common Neutral Losses is Yes
- Total Fragments Found is greater than or equal 1

Figure 5. Drug-Related Properties Filter.

### Worked Example

To illustrate the power of the Waters SELECT SERIES Cyclic Ion Mobility Mass Spectrometer combined with the waters\_connect Metabolite Identification application software, this platform was used for the analysis of plasma following the oral administration of fasiglifam to Sprague-Dawley rats at 50 mg/kg. The protein-precipitated plasma was analyzed by reverse-phase UPLC-MS with detection in the negative ion ESI mode. The mass spectrum obtained for the parent compound is shown in Figure 6. In the upper trace, Figure 6(i), we see the deprotonated parent ion for fasiglifam  $m/z = 523.1809$ , and in the lower trace, diagnostic MS/MS fragment ions at  $m/z = 479.1899$ , 403.1549, 359.1650, 319.1340, 192.0427, and 148.0527 (Figure 6(ii)). A blue icon by a product ion indicates that the software has assigned a plausible structural explanation for that product ion based on systematic disconnections of the structure.

Item name: TAK875\_RP\_plasma\_Neg\_Oct21\_0012 Channel name: Low energy : Time 6.9044 +/- 0.0159 minutes : Drift Ti...  
Item description: Plasma\_1\_4\_1hr\_PO-50



Item name: TAK875\_RP\_plasma\_Neg\_Oct21\_0012 Channel name: High energy : Time 6.9044 +/- 0.0159 minutes : Drift...  
Item description: Plasma\_1\_4\_1hr\_PO-50

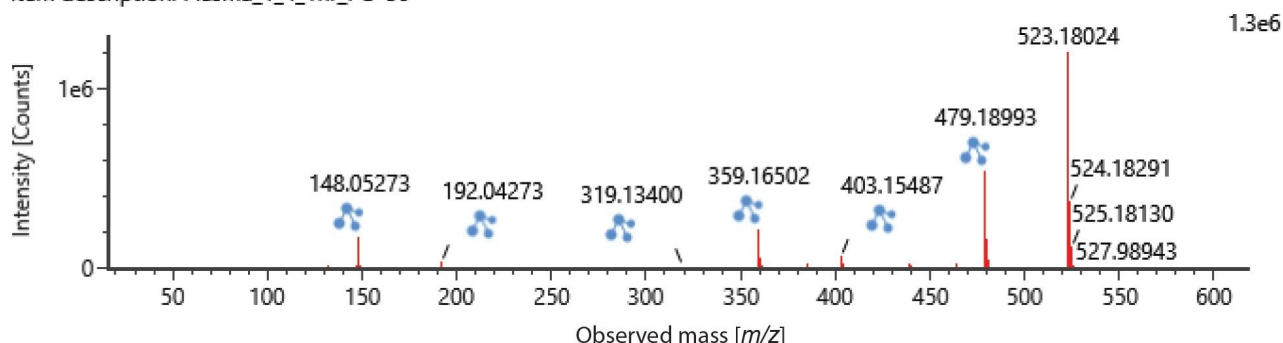


Figure 6. Precursor (upper trace) and product ion (lower trace) spectra of fasiglifam.

The major and previously reported metabolites of fasiglifam were identified using a combination of targeted screening using library entries, diagnostic fragment ions, common neutral losses and established metabolic cleavage, functionalization, and conjugation reactions. For example, the glucuronide metabolite of fasiglifam, eluting with a retention time  $t_R = 6.26$  minutes with a deprotonated molecular ion  $m/z = 699.2113$  is shown in Figure 7, with diagnostic fragment ions at  $m/z = 523.1786$ , corresponding to a neutral loss of the glucuronide moiety, and the glucuronide itself as a product ion. Complete analysis of these samples resulted in the detection of the previously reported metabolites<sup>2,3</sup> together with several new, and previously unreported metabolites, in which the biotransformations appear to be associated with the substituted dihydrobenzofuran moiety. The structure of these new metabolites is currently under further investigation.

Item name: TAK875\_RP\_plasma\_Neg\_Oct21\_0067  
Item description: Plasma\_1\_13\_12hr\_PO-50

Channel name: High energy : Time 6.2609 +/- 0.0160 minutes : Drift Times: 12.57 +/- 0.36 ms

5.58e3

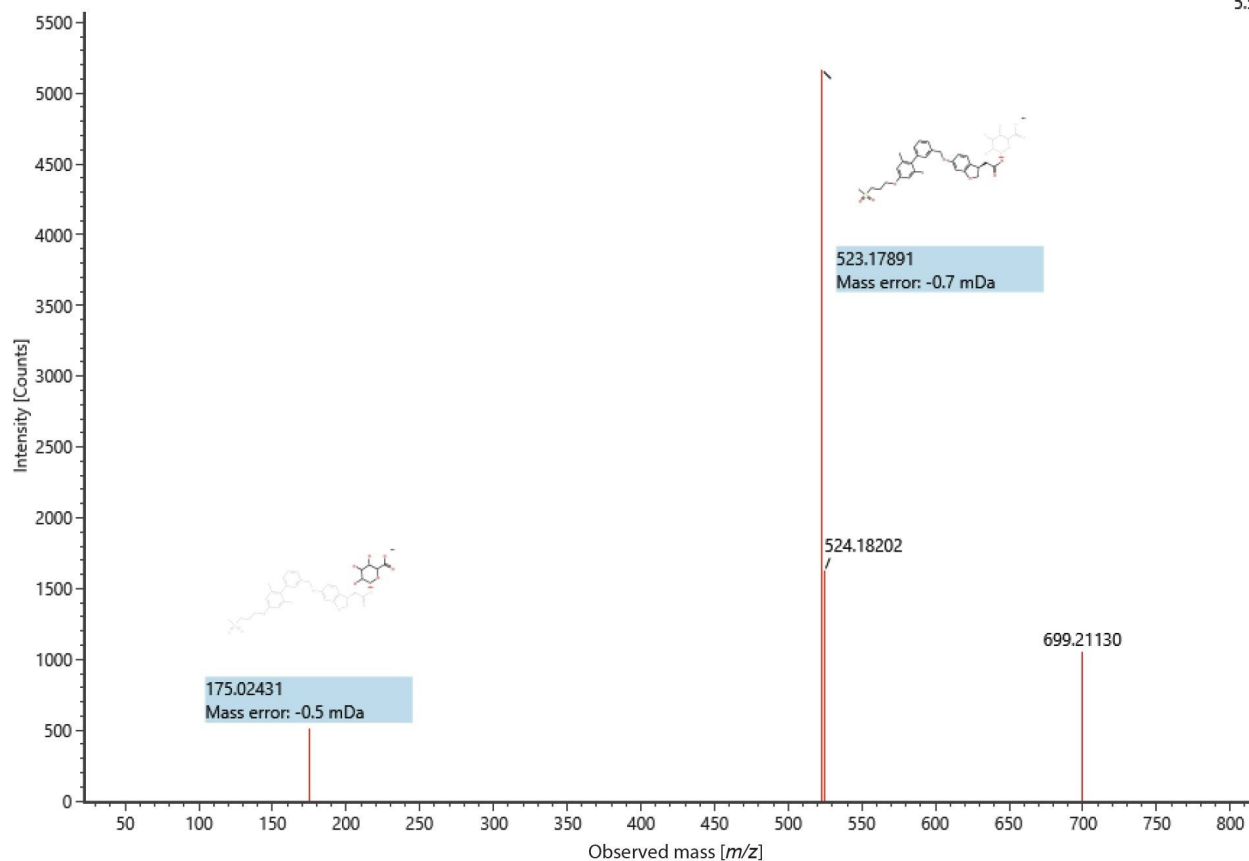


Figure 7. Product ion spectrum of major fasiglifam glucuronide metabolite.

## Localization of Site of Metabolism

One of the most challenging, but essential, tasks in drug metabolite identification is the localization of the site of metabolism on the molecule. This can be a time-consuming task requiring scientists with experience in structural analysis and metabolic transformations. The waters\_connect Metabolite Identification Application supports this process using systematic bond disconnections and chemical intelligence to suggest or in some cases identify the site of drug metabolism. For example, Figure 8 demonstrates how the software helps the drug metabolism scientist localise the site of metabolism for a previously unreported M-2H+O metabolite of fasiglifam. The software highlights the potential sites of metabolic transformation, with green indicating the most likely sites of metabolism and orange indicating possible, but less likely, sites of metabolism, based on the number of conserved or shifted product ions when compared with the product ion spectrum of the parent drug.

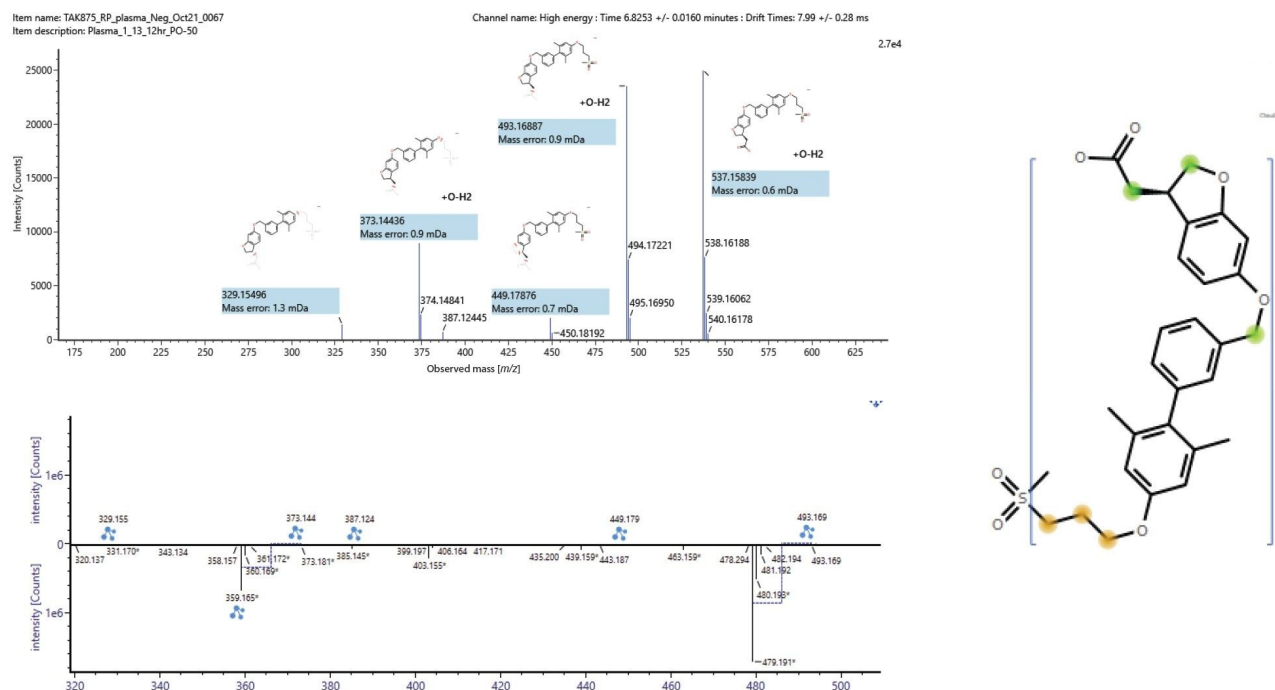


Figure 8. Localization of Site of Metabolism.

## Summary Plots and Visualization

The waters\_connect Metabolite Identification application facilitates the generation of plots and reports from the reviewed data once an analysis is complete. One of the most useful of these, the summary plot, is depicted in Figure 9, and shows how the concentration of fasiglifam and its major metabolites varies as a function of time post-dose. Here we can see that fasiglifam and the major metabolites follow a similar elimination profile with a maximum concentration observed at 9 h and a gradual reduction in concentration of the metabolites over the following 96 h. However, it is evident that even after 96 h the parent drug and metabolites are still not fully eliminated from the systemic circulation.

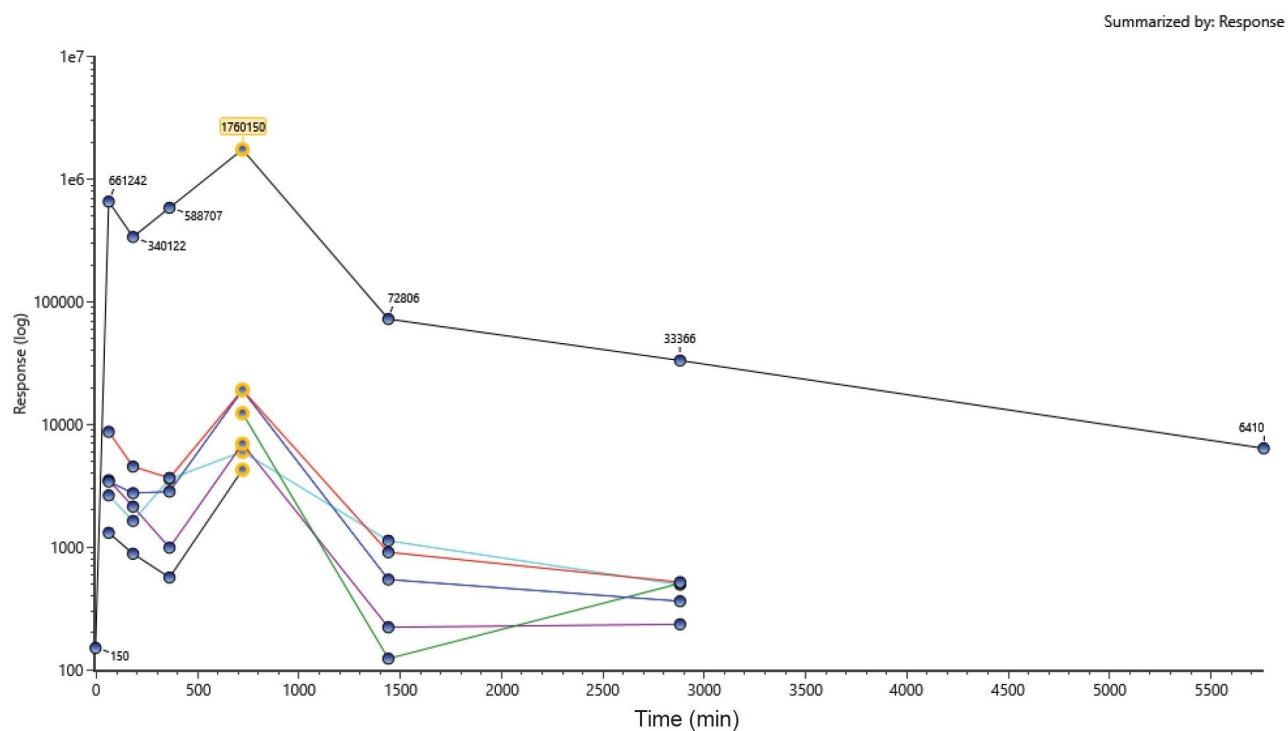


Figure 9. Summary plot of drug and metabolite concentration with sampling time.

Figure 9. Summary plot showing log (response) for the parent drug and a variety of observed metabolites as a function of time post dose (h). Reporting waters\_connect has a powerful and flexible reporting function allowing complete customization of outputs based on customer needs. For example, Figure 10 shows a summary table of the metabolites observed in the 9 h sample, automatically labelled in order of increasing retention time.

Item name: TAK875\_RP\_plasma\_Neg\_Oct21\_0067, Sample position: , Replicate number: 1

| Label | Component name       | Formula     | Observed m/z | Mass error (ppm) | Observed RT (min) | Observed CCS (Å <sup>2</sup> ) | Has Common Neutral Losses | Has Common Fragment Ions | Total Fragments Found | Expected Fragments Found | Response |
|-------|----------------------|-------------|--------------|------------------|-------------------|--------------------------------|---------------------------|--------------------------|-----------------------|--------------------------|----------|
| M1    | tak875 M-I           | C19H22O5S   | 361.1111     | -1.2             | 6.03              | 199.70                         | Yes                       | No                       | 1                     | 0                        | 1908     |
| M2    | tak875+O             | C29H32O8S   | 539.1739     | -1.1             | 6.22              | 219.80                         | Yes                       | Yes                      | 6                     | 1                        | 6020     |
| M3    | tak875-G             | C35H40O13S  | 699.2113     | -0.5             | 6.26              | 246.26                         | No                        | No                       | 1                     | 0                        | 2523     |
| M4    | tak875+O2            | C29H32O9S   | 555.1687     | -1.2             | 6.32              | 222.93                         | No                        | Yes                      | 4                     | 2                        | 4281     |
| M5    | tak875+O-H2          | C29H30O8S   | 537.1585     | -0.7             | 6.34              | 220.17                         | Yes                       | No                       | 3                     | 0                        | 1036     |
| M6    | tak875+O2            | C29H32O9S   | 555.1688     | -1.1             | 6.41              | 224.27                         | Yes                       | No                       | 1                     | 0                        | 787      |
| M7    | tak875-tau           | C31H37NO9S2 | 630.1836     | -0.2             | 6.44              | 238.40                         | Yes                       | No                       | 1                     | 0                        | 3834     |
| M8    | tak875+O             | C29H32O8S   | 539.1743     | -0.3             | 6.46              | 220.79                         | Yes                       | No                       | 5                     | 0                        | 3812     |
| M9    | tak875+O2            | C29H32O9S   | 555.1690     | -0.7             | 6.53              | 221.09                         | No                        | No                       | 12                    | 0                        | 19155    |
| M10   | tak875+O             | C29H32O8S   | 539.1738     | -1.2             | 6.54              | 220.25                         | No                        | No                       | 7                     | 0                        | 1162     |
| M11   | tak875+O-H2          | C29H30O8S   | 537.1586     | -0.5             | 6.60              | 219.97                         | Yes                       | No                       | 5                     | 0                        | 3173     |
| M12   | tak875+O-H2          | C29H30O8S   | 537.1583     | -1.1             | 6.83              | 218.96                         | Yes                       | No                       | 5                     | 0                        | 12403    |
| M13   | tak875-CH2(cleavage) | C28H30O7S   | 509.1636     | -0.8             | 6.83              | 214.82                         | Yes                       | No                       | 4                     | 0                        | 2277     |
| M14   | tak875-H2            | C29H30O7S   | 521.1636     | -0.6             | 6.98              | 217.82                         | Yes                       | Yes                      | 8                     | 2                        | 19205    |
| M15   | tak875-H2            | C29H30O7S   | 521.1638     | -0.3             | 7.06              | 218.05                         | Yes                       | Yes                      | 7                     | 1                        | 6973     |

Figure 10. Automatically generated report object documenting the metabolites found in the 9 h sample.

## Conclusion

This combination of a data-rich, generic, and robust data acquisition method, combined with powerful analysis tools allows highly complex datasets to be reduced to a set of tractable outcomes which can be reviewed in a relatively short period of time by the drug metabolism scientist. Known metabolites can be included in the analysis method, and a systematic search for other likely metabolites is facilitated by the use of powerful filters which rank components based on their drug-like properties. Ion mobility-enabled mass spectrometry allows clean product ion spectra to be generated without the need to create complex data-dependent acquisition schemes, and further affords compound-specific CCS values which can be used to distinguish isobaric metabolites and track metabolites across chromatographic methods.

## References

1. Li X, Zhong K, Guo Z, Zhong D, Chen X. Fasiglifam (TAK-875) Inhibits Hepatobiliary Transporters: A Possible Factor Contributing to Fasiglifam-Induced Liver Injury. *Drug Metab Dispos.* 2015;43(11):1751–9.

2. Otieno MA, Snoeys J, Lam W, Ghosh A, Player MR, Pocai A, Salter R, Simic D, Skaggs H, Singh B, Lim HK. Fasiglifam (TAK-875): Mechanistic Investigation and Retrospective Identification of Hazards for Drug Induced Liver Injury. *Toxicol Sci.* 2018;163(2):374–384.
3. Kogame A, Lee R, Pan L, Sudo M, Nonaka M, Moriya Y, Higuchi T, Tagawa Y. Disposition and Metabolism of the G Protein-Coupled Receptor 40 Agonist TAK-875 (Fasiglifam) In Rats, Dogs, and Humans. *Xenobiotica.* 2019;49(4):433–445.

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