Analysis of an Adulterated Herbal Medicinal Product Using Ultra-Performance Liquid Chromatography Coupled with QTOF Mass Spectrometry

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ABSTRACT

The reports of severe adverse effects and fatalities associated with herbal medicinal products adulterated with synthetic compounds have raised global concerns. The objective of this study is to analyze one commercial herbal medicinal product suspected to be adulterated with synthetic drugs in order to identify potential adulterants, to verify if the product contained the herbs listed as ingredients in label claim and to determine quality consistency among different batches of the product. Analyses of suspected product obtained from seven different batches were performed using ultra performance liquid chromatography coupled to quadrupole time-of-flight mass spectrometry (UPLC-Q-TOF-MS) with multiple data processing tools and multivariate analyses. In addition, 23 individual powdered herbs (12 as per label claim and 11 suspected herbs), 11 marker compounds of the labeled herbs and five suspected synthetic drugs as adulterants were also concurrently analyzed to have clear understanding of product composition. Based on our analysis, the major ingredients of studied product were found to be 5 synthetic compounds: caffeine, chlorphenamine, piroxicam, betamethasone and oxethazaine. Three of them have been found to exceed their recommended doses. From the herbal composition analysis, GanCao (Glycyrrhizae radix et rhizoma) was found to be the main ingredient, which is not among the claimed 12 herbs that were supposed to be in the product. Other herbs detected as minor ingredients were MuGua (Chaenomelis fructus), DangGui (Angelicae sinensis radix), and HuangQi (Astragalui radix), which are among the 12 herbs that were supposed to be in the product. Based on our results we demonstrated that UPLC-QTOF MS is an effective and versatile tool for the analysis of herbal medicinal products. It is highly desirable to have a streamlined process with automatic workflow and fit-for-purpose database to increase efficiency and productivity of sample analysis. Results of this work also highlight the need for the better quality control and regulatory measures to protect consumers from the potentially harmful effects of such adulterated products.

Key words: Synthetic adulterants, Adulteration, UPLC-QTOF-MS, Herbal products, Data independent acquisition, Multi-Variate Statistical Analysis

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INTRODUCTION

Herbal medicinal products (HMPs) are popular among many people as a choice for part of their healthcare. These products are primarily used for general health maintenance, well-being and for the treatment of self-limiting ailments. According to the World Health Organization (WHO) report, the global sales of herbal medicines exceeded $83 billion in 2011[1]. The main reasons for the increased popularity of HMPs include general perception of such products as safe being natural; their ready availability and affordability compared to prescription drugs and desire of consumers for self-treatment[2-3].

However, in recent years, reports of adverse events associated with the use of HMPs has raised growing concerns about their quality, safety and efficacy[3-8]. These concerns are not entirely unreasonable since there are both internal factors and external factors that do affect the quality and safety of HMPs[7-9]. Internal factors include intrinsic toxicity associated with certain plants and possibilities for potential herb-drug interactions should a patient take HMPs and synthetic drugs simultaneously[7-9]. Externally, there are increasing reports of HMPs being adulterated with undeclared drugs and their synthetic analogues[7-9]. There are also reports of the presence of toxic contaminants (e.g. pesticide residues, toxic heavy metals, mycotoxins, microbial contamination etc.) in these products[7-10]. Among those factors, adulteration with synthetic drugs is reported as the main cause of adverse events associated with the use of HMPs[5-7,11].

Economically motivated adulteration of HMPs to achieve the claimed therapeutic effects could pose a serious health risk to the oblivious consumer; in some cases these have even resulted in deaths[5-7,11]. For these reasons, there is a strong global demand for tighter regulation and a higher standard of quality control (QC) of HMPs. Proper selection and effective use of analytical tools are also essential and critical during the QC testing for HMPs.

A variety of analytical methods, such as thin layer chromatography (TLC), high performance thin layer chromatography (HPTLC), high performance liquid chromatography (HPLC) with UV detection, gas chromatography (GC),
capillary electrophoresis (CE), mass spectrometry (MS) and combination of MS with different chromatographic methods such as GC-MS, liquid chromatography-mass spectrometry (LC-MS), CE-MS etc are employed for the analysis of HMPs for quality control including screening for adulteration with synthetic drugs[12-14]. In addition, various spectroscopic techniques such as infrared (IR), near infrared (NIR) and Nuclear Magnetic Resonance (NMR) are also used[12-14]. The merits, short comings and applications of these techniques have been extensively reviewed in previous reports[12-14]. TLC and HPTLC methods are simple and cheap methods that have been used for the identification of active components and adulterants of plant extracts and HMPs for which reference standards are available. However, they are not particularly useful for the identification of unknown active compounds and adulterants and suffers from low sensitivity and limited separation capability[12-14]. HPLC with UV detection is one of most commonly used methods in qualitative and quantitative analysis of HMPs. Although HPLC based methods offers advantages of higher sensitivity, separation power and reproducibility, they have limited scope in identification of unknown ingredients and undeclared and/or unknown adulterants[12-14]. GC-MS is powerful technique for the analysis of HMPs but its applicability is limited by requirement of volatility and thermal stability of analytes[12-14]. Among above analytical technologies, LC-MS is one of the most popular choices of technology because of its high selectivity and sensitivity in analyzing complex HMP matrices compared to other techniques[12-16]. Especially, methods based on liquid chromatography coupled with high resolution mass spectrometry (LC-HRMS) are gaining popularity. The main reason for the increased use of LC-HRMS based methods is their ability to separate, identify and quickly confirm the identities of known and unknown ingredients[12-16]. High resolution mass spectrometry provides valuable information on elemental compositions of unknown components for database search, one of the most essential steps for compound identification[15-16].

One of the LC-HRMS methods employed is ultra performance liquid chromatography coupled with quadrupole time of flight mass spectrometry (UPLC-QTOF-MS) with data independent acquisition (DIA)[17-20]. In such hyphenated method, the UPLC offers rapid sample separation with high resolution, speed and sensitivity[17-19,21-22] while the QTOF mass spectrometer (QTOF-MS) offers higher mass resolution at faster spectral acquisition rate compatible with rapid chromatographic separation without compromising sensitivity[17-20]. DIA is widely used data acquisition strategy for LC-HRMS analyses. DIA allows simultaneous detection of parent ion and fragment ions, providing information on all ionizable species present in a chromatographic separation so that potential hits obtained from database searches can be confirmed through fragmentation patterns without the need of further sample injection[20,22]. In addition, DIA strategies generates complete data sets which could be subjected for retrospective multiple data mining processes and steps to get answers to the different questions with a particular sample[20,22,23]. However, such strategies generate large and complex data. Therefore, in addition to instrument hardware configuration and data acquisition of injected samples, utilizing fit for purpose informatics solutions for data processing and results generation is also important.

In this paper, we show the utility of UPLC-QTOF-MS coupled with informatics tools to analyze one commercial herbal medicinal product suspected to be adulterated with synthetic drugs. The HMP in question was supposed to contain a simple blend of 12 herbs, whose powders were filled into hard gelatin capsules. It is a popular product marketed for the relief of arthritic pain. However, in June 2011, a regulatory agency from a European country posted a public warning against the consumption of this product as the analyses performed had shown that the product was adulterated with undeclared prescription drug substances (chlorphenamine, oxetacaine, piroxicam and betamethasone) and caffeine[24]. In consequence, a contract research organization (CRO) in the UK received a request to perform comprehensive analytical testing to gain complete knowledge of product ingredients.

The objectives of this analysis were to confirm the presence of synthetic drugs as adulterants, to verify if the product contained the 12 herbs listed as ingredients in label claim and to determine batch to batch variation to investigate if the capsules are made consistently. In order to achieve these objectives, analyses using UPLC-QTOF-MS in DIA acquisition mode were performed using multiple data mining tools and multivariate analyses.

**MATERIALS AND METHODS**

### 1. Materials and Chemicals

All samples of capsules and reference standards were supplied by Quay Pharma (Deeside, UK). These included: the HMP commercial products to be tested (seven batches); 23 individual herbal powders; 12 of them are claimed herbal ingredients and 11 of them are suspected herbal ingredients; 11 chemical marker reference standards that were associated with the 12 herbs; and 5 synthetic compounds that were suspected to be spiked into the capsule. Table 1 shows the list of the 12 claimed herbal ingredients as along with their chemical marker reference standards (as per 2010 Chinese Pharmacopoeia).

The 11 marker reference standards supplied were: Astragaloside IV, Chlorogenic acid, Cinnamaldehyde, Corydaline, Ferulic acid, Hesperidin, Oleanolic acid, Osthole, Paeniflorin, Protocatechuic acid, Ursolic acid. And the 5 synthetic compounds are: Betamethasone, Caffeine, Chlorpheniramine Maleate, Oxetacaine, and Piroxicam. The additional 11 herbs that were send as individual powders are: Ganjiang (干姜) zingiberis Rhizoma, Lianqiao (连翘) Fructus Forsythiae Suspensae, Baizhi (白芷) Angelicae Dahuricae Radix, Xuanshen (玄参) scrophulariae Radix, Sangjisheng (桑寄生) Ramulus Loranthi Seu Visci, Cangzeri (苍耳子) Fructus Xanthii Siberici, Gancao (甘草) Glycyrrhizae Radix ET Rhizoma, Kushen (苦参) Sophora Flavescent, Shudihuang (熟地黄) processed Radix Rehmanniae, Fangfeng (防风) Radix Ledebouriellae Divaricateae, Longdan (龙胆) Gentianae Radix ET Rhizoma.
Fisher Optima LC-MS grade acetonitrile was obtained from ThermoFisher Co (Waltham, MA, USA). Formic acid and Leucine Enkephaline were purchased from Sigma Aldrich (St. Louis, MO, USA). Deionized water was obtained in our lab via a Milli-Q water purification system from Millipore (Bedford, MA, USA).

2. Sample Preparation
Each hard gelatin capsule was opened to obtain 30 mg of the sample powder and placed into a 10 mL volumetric flask followed by addition of 5 mL of acetonitrile. The solution was subjected to ultrasonication for 15 minutes. After ultrasonication, 5 mL of deionized water was added to that solution and it was further subjected to ultrasonication for another 15 min. After ultrasonication, the solution was filtered through 0.2 μm PVDF filter membrane before injecting in LC/MS. The final concentration of the HMP sample solution used for LC/MS injection was 3 mg/mL. 7 individual solutions were prepared, one for each batch using the same above mentioned procedure.

A mixture solution containing the 11 reference herbal standards was prepared by using 3 mg of each standard by the same procedure that was used for HMP samples. The final concentration of each of the standards in the solution mixture was 0.3 mg/mL. This solution was further diluted 30-fold with acetonitrile/water (1:1) to obtain a solution of 10 μg/mL level for LC/MS injection. Similarly, a mixture solution that contained the 5 synthetic compound standards was prepared in the same way as the reference herbal standard solution mixture with final concentration of 10 μg/mL for LC/MS analyses.

3. Ultra performance liquid chromatography-mass spectrometry
The LC separation was performed on a Waters ACQUITY I-Class UPLC system (Waters Corporation, Milford, MA) with an ACQUITY UPLC HSS T3 column (1.8 μm, 2.1 × 100 mm). The column temperature was set at 45 °C. The flow rate was kept at 0.6 mL/min. Mobile phase consisted of water with 0.1% formic acid (A), and acetonitrile (B). The chromatographic separation was achieved by gradient elution from 1% B to 70% B in 26 minutes with additional 2 minutes re-equilibration. The total run time was 28 minutes, and the injection volume was 2 μL.

The MS detection was performed on a Waters Xevo G2 QTOF MS System (Waters Corporation, Milford, MA). The data acquisition mode was MS² (where “E” stands for elevated) which allows simultaneous acquisition of MS spectra at low and high collision energies (CE). The low CE scan provides intact parent ion information, while the high CE scan provides fragment ion information. These low CE and high CE scans are then aligned by their retention time so that the fragments are linked to the correct parent ion(s) for increased accuracy and confidence in compound identification. Samples were analyzed by both ESI positive and ESI negative ionization modes. The source and desolvation temperatures were set at 120 °C and 450 °C respectively. The desolvation gas flow was set at 900 L/Hr and Lock-Spray™ was used to ensure mass accuracy and reproducibility. The lock mass compound used was leucine enkephaline (2 ng/mL). The capillary voltage and cone voltages were set at 3 kV and 30 V respectively. The collision energies were set at 5 eV for low energy scan, and 15-40 eV ramp for high energy scan. The UPLC/MS data acquisition was controlled by Masslynx 4.1 Mass Spectrometry Software (Waters Corporation, Milford, MA).

4. Data processing
All data processing was performed using MassLynx 4.1 with different application managers. For targeted analysis, to determine if the capsules contained the 5 synthetic adulterants, and to determine if the capsules contained the 13 herbs claimed by the supplier, TargetLynx Application Manager was used. For non-targeted analysis, to determine the consistency
of the batches and identify key contributing markers for sample grouping, MarkerLynx Application Manager was used. Multivariate analysis (MVA) was performed using the EZinfo statistical tool from Umetrics (CA, USA).

RESULTS AND DISCUSSION

1. Detecting synthetic compounds spiked into the capsules

In order to confirm the presence of synthetic adulterants, concurrent analyses of samples and reference standards of five suspected prescription drugs were performed by MS strategy to obtain information on intact parent ions and their respective fragments in a single LC-MS injection. During data processing, the low CE scan was used at the initial step to screen adulterant identity and the high CE scan was used to confirm the result of initial scanning obtained from the low CE scan. The following steps were used to identify and confirm the presence of synthetic adulterants.

Firstly, peaks corresponding to expected accurate masses of five adulterants were identified using extracted ion chromatograms (XICs). Using accurate masses of those peaks, corresponding elemental compositions were obtained and matched with those of suspected drugs. Formulae of five peaks matched with the formulae of the target compounds indicating that those five peaks correspond to five synthetic adulterants. The measured exact mass of parent ions [M+H]⁺ were all within very small mass errors indicating a positive match (as shown in the table embedded within Figure 1). The second step is to match the retention time of identified five peaks with those of reference standards. Retention times of reference standards and identified five peaks in the samples were found to be identical. The final step of confirming the presence of adulterants was to compare the fragmentation patterns of the sample peak vs. the reference standards. The fragment ions of suspected peaks in the samples matched with those of reference standards, thus confirming the adulteration of capsules with five synthetic compounds (chlorphenamine, oxethacaine, piroxicam, caffeine and betamethasone). These substances were not declared on the product label.

Chlorphenamine, oxethacaine, piroxicam and betamethasone are prescription-only drugs and should only be taken after consulting a medical practitioner. Piroxicam is non-steroidal anti-inflammatory drug (NSAID) which is used as a pain killer and antipyretic drug. Betamethasone is corticosteroid, Oxetacaine is local anaesthetic and chlorpheniramine is an anti-histamine which is used to treat allergies.

Piroxicam and betamethasone have beneficial anti-inflammatory therapeutic effects in rheumatoid arthritis. However, the reason for the presence of oxethacaine, chlorpheniramine and caffeine is unclear for this indication. Furthermore, the sample BPI chromatogram (Figure 1) indicates that chlorphenamine, oxethacaine, piroxicam and caffeine are the major sample peaks which imply that adulterants are present at higher concentrations than other natural compounds in the sample. Therefore, the detection was not particularly demanding in terms of instrument sensitivity as in most cases of adulteration with synthetic compounds, they are

Figure 1. Base Peak Ion (BPI) Chromatogram obtained from the UPLC-QTOF MS full scan (Low CE) for the Herbal Medicinal Product capsule. All five suspected adulterants were detected and identified.
typically spiked at relatively high levels. To determine if the levels of these prescription drugs found as adulterants are comparable to their prescribed doses, we performed more analyses to quantify these adulterants.

Quantifications of five adulterants were performed using the TargetLynx Application Solution, which was a specific solution for quantitative analysis within MassLynx. Table 2 shows the determined concentrations of five adulterants in capsules. Table 2 also shows comparison of calculated amount of those five adulterants per daily dose of capsules with their recommended daily dose. The approved dose of these synthetic drugs was taken from British National Formulary (BNF) and Proprietary Association of Great Britain (PAGB[25]).

As can be seen from the Table 2, the calculated amount of betamethasone, oxethazaine and chlorpheniramine per daily dose of those capsules exceeds their recommended prescription doses. The dose of the corticosteroid betamethasone was found to be double its recommended dose. The long-term use of NSAIDS may result in increased risk of severe cardiovascular side effects such as strokes and myocardial infarction.[12]. For steroids, it is reported that their long term usage could lead to Cushings syndrome and its associated symptoms such as skin thinning, muscle wasting and osteoporosis.[10]. In addition, the capsules evaluated in this study were adulterated with cocktail of multiple drugs whose drug-drug interaction and herb-drug interactions are not known when consumed together. These findings clearly show that consumption of such adulterated capsules could potentially result in significant health problems. The results of this study and several reports of adulteration of HMPs documented in literature highlights the importance of increasing public awareness and having more stringent regulatory control of HMPs.[5,7,11-12].

2. Determining the herbal content of the capsule
After confirming the presence of synthetic adulterants, we examined the herbal ingredients of the product. According to the supplier’s claim, there are 12 TCM herbs present in this capsule; Table 1 listed the 12 TCM herbs and the required testing markers for each of the herb according to the 2010 edition of the Chinese Pharmacopeia. The goal for this part of the testing was to get a clear understanding of the herbal content of the capsule through the UPLC/QTOF MS analysis. Our first task was to find evidence of existence of the 12 claimed herbs. The presence of a particular herb was assessed by identifying markers according to 2010 edition of Chinese Pharmacopeia. The samples were analyzed concurrently with 23 herbs (includes 12 labeled and 11 suspected herbs) and reference standards of respective marker compounds of those 23 herbs.

The presence of marker compounds of respective herbs was checked by generating XIC from their expected accurate mass and final confirmation was done by comparing retention time and fragment ions from MS² spectra. For the identified markers, their peak area in respective individual herbs and capsules from different batches were used to determine the variation in concentration of these markers in different batches (Figure 2). The herbs associated with the detected markers are also labeled on Figure 2 which indicates that we were only able to find evidence of three herbs to be present in this capsule out of the 12 claimed herbs. They are MuGu (Chuanxiong Rhizome), DangGui (Angelicae Sinensis Radix), and HuangQi (Codonopsis Radix). The peak area of markers oleoanolic acid, furalic acid and calycosin also indicated variation in concentrations of these three markers in seven batches (Batch A to G). The herb ChangZhu (Atractylodis Rhizome) contains mostly volatile essential oil and its constituents are normally analysed by GC-MS. Therefore, in our study it was not possible to ascertain its presence or absence in the tested product. Our second task was to seek the answer to this question: regardless of the ingredient content identified from these capsules, are these capsules at least manufactured consistently? Figure 3 shows the overlaid BPI chromatograms comparison of the seven batches of the capsules. Visually, the chromatograms of seven batches of capsules appeared to be indistinguishable from each other. The plot shown in Figure 3 has normalized y-axis meaning all chromatograms displayed are based on the same scale indicating that not only the number of peaks but the relative height of the peaks also appeared to be very similar from batch to batch.

To ensure a thorough investigation of the chemical profiles of the samples, the MarkerLynx application manager was used to generate marker matrix for multivariate analyses. MarkerLynx offers the ability to perform Multivariate Statistical Analysis (MVA) for the UPLC/QTOF MS data. Details of the MarkerLynx operation has been discussed elsewhere[26-28]. Briefly, MarkerLynx performs data deconvolution to convert the three dimensional LC/MS data

<table>
<thead>
<tr>
<th>Drug</th>
<th>Indication</th>
<th>Amount per Capsule (mg)</th>
<th>Daily exposure based on labelled dose (mg/day)</th>
<th>Recommended Dose (mg/day) (from BNF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Betamethasone</td>
<td>Anti-inflammatory</td>
<td>5</td>
<td>10</td>
<td>0.5 to 5 mg</td>
</tr>
<tr>
<td>Caffeine</td>
<td>Stimulant/diuretic</td>
<td>2</td>
<td>4</td>
<td>50 mg</td>
</tr>
<tr>
<td>Chlorpheniramine maleate</td>
<td>Antihistamine</td>
<td>2.5</td>
<td>5</td>
<td>4 mg (adult)</td>
</tr>
<tr>
<td>Oxethazaine</td>
<td>Anaesthetic</td>
<td>6</td>
<td>12</td>
<td>2 mg (6-12 years)</td>
</tr>
<tr>
<td>Piroxicam</td>
<td>Rheumatic pain</td>
<td>5</td>
<td>10</td>
<td>10 mg</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20 mg (adult)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5 (&gt; 6 years)</td>
</tr>
</tbody>
</table>
(retention time, m/z, and intensity) into a two dimensional data matrix: Exact Mass Retention Time (EMRT) pair vs. Intensity\textsuperscript{[26-28]}. It then allows automatic export of the marker matrix to EZinfo (Umetrics, CA, USA), a statistical tool embedded within the MarkerLynx application manager, to perform MVA\textsuperscript{[26-28]}.

For MVA studies, six replicates of capsule samples from each of the seven different batches were analyzed. Figure 4 shows the Scores plot of the Principle Component Analysis (PCA) of the seven batches of the HMP capsules. PCA is unsupervised analysis and score plot generated from PCA shows trends, patterns and grouping among different batches. The seven batches formed three groups: batches A to D, batches E and F and batch G. Batches A to D, batches E and F, and batch G, which showed certain degree of batch to batch variations. To narrow down the key contributing markers that accounted for the observed grouping, Orthogonal Partial Least Square-Discriminant Analysis (OPLS-DA) was further conducted by comparing the randomly chosen two groups of samples from PCA score plot using EZinfo. OPLS-DA is supervised analysis where pre-existing knowledge is required to determine differentiating markers between two chosen groups Figure 5 shows the S-Plot of the OPLS-DA of batch G (BG) vs. batches B, E, and F (BEF) with x-axis
being the covariance and y-axis being the correlation. The markers on both ends of the S-Plot represent the ingredients that have the most impact on variation accounted for the separation of these two groups. These markers can be selected and automatically exported to EZinfo for further analysis as shown in Figure 5.

From the above MVA studies, the key contributing markers were all identified with information on their respective retention times and exact masses. This information was then utilized to mine the LC/MS data that were already obtained for each of the 23 individual herbs to see if any of the markers were also present in any of those 23 herbs. The logic here is that from key contributing markers, we could trace back to the corresponding herbs that dominated the variability among different batches. To accomplish this task, the TargetLynx application manager was again utilized by creating a target analyte list consist of these key markers. This was done on all 23 individual herbs. As a result, many of the key markers that were identified from the MVA analysis were traced to the herb GanCao (Glycyrrhiza radix et rhizoma).
To further confirm the influence of GanCao in batch-to-batch variation of capsules, the peak area of markers for GanCao were determined in samples from all seven batches and added into the plot shown in Figure 2. The resulting new plot is shown in Figure 6, which clearly shows that GanCao is the main herbal ingredient of the capsules. However, GanCao is not among those 12 listed herbs. This shows that capsules were not manufactured as per the label claim. This further highlights the need for regulatory control to ensure the good quality of marketed HMPs.

From the above analyses, GanCao was found to be the dominating herbal ingredient of this product, along with MuGua (Chaenomelis fructus), DangGui (Angelicae sinensis radix), and HuangQi (Astragali radix) as the other detectable herbs. MuGua and HuangQi were listed among 12 labeled herbs. It is difficult to conclude that absolutely no other herbs are present in this product; however, the results clearly indicated that even if there are other herbs, they merely exist at trace levels. These findings were consistent from batch to batch. The concentration of these three herbs was also found to be different for samples obtained seven samples (Figure 4).

In summary, the analyses of samples from different batches and comparison with 23 herbs clearly show quality lapses in manufacturing.

CONCLUSION

UPLC/QTOF MS analysis in MS^E mode employed in this study provided a clear picture of the ingredients in the analyzed capsules. The analytical strategy based on UPLC/QTOF MS coupled with various informatics tools used in this study can be effectively applied for targeted and un-targeted analyses of HMPs to screen for the presence of adulterants and ingredients of herbal origin. Based on our analysis, the dominating major ingredients of studied HMP capsule were found to be 5 synthetic compounds: caffeine, chlorphenamine, piroxicam, betamethasone and oxethazaine. Three of them have been found to exceed their recommended doses. From the herbal composition analysis, GanCao (Glycyrrhiza radix et rhizoma) was found to be the main ingredient, which is not among the claimed 12 herbs that were supposed to be in the product. Minor herbal ingredients detected were MuGua (Chaenomelis fructus), DangGui (Angelicae sinensis radix), and HuangQi (Astragali radix), which are among the 12 herbs that were supposed to be in the product.

Analytical testing using a fit-for-purpose tool is required to ensure reliable results. UPLC-QTOF MS is an effective and versatile tool for targeted and un-targeted analyses. Informatics tools play a vital role in obtaining meaningful answers from large amount of data generated from such analyses. The analysis of large and complex LC-MS data can be extremely laborious as often there is a need to identify unknowns. A streamlined process with automatic workflow and fit-for-purpose database is desirable for simple and efficient identification of ingredients in complex HMP samples. Lastly, results of this work further underscore the need for better quality control and regulatory measures to protect consumers from the potentially harmful effects of adulterated HMPs.

REFERENCES


