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Internal Standard Compounds for Quantitative Determination of Bile Acids by Gas Chromatography

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Gas chromatography is well recognized as a useful tool with several advantages for the analysis of bile acids as well as various compounds. In gas chromatographic analysis, bile acids in an analytical sample are subjected to a number of complicated procedures involving many steps such as extraction, fractionation, solvolysis, hydrolysis, derivatization and injection to the gas chromatograph. These procedures result in the loss of bile acids in the analytical sample. The addition of suitable internal standard compound(s) into the analytical sample prior to the extraction of bile acids is indispensable for an accurate determination of bile acids. There are two methods for the quantitative determination of bile acids in a biological sample by gas chromatography: one is the determination of total bile acid amounts in the sample. The other is the determination of bile acid amounts in each fraction after group separation of bile acids in the biological sample using an ion exchange gel column. The addition of 7β,12α-dihydroxy-5β-cholanoic acid or 7β,12β-dihydroxy-5β-cholanoic acid as an internal standard compound is useful for the former method. On the other hand, the addition of 7β,12β-dihydroxy-5β-cholanoic acid, glyco-7α,12α-dihydroxy-5β-cholanoic acid, tauro-7α,12β-dihydroxy-5β-cholanoic acid and glyco-7β,12α-dihydroxy-5β-cholanoic acid 7-sulfate is a suitable combination as internal standard compounds for the latter method.

Key words: bile acids; biological sample; gas chromatographic analysis; internal standard compounds; quantitative determination

The use of gas chromatography in investigation of bile acids

Gas chromatography is well recognized as a useful tool with several advantages for the analysis of bile acids as well as various compounds. It especially has good sensitivity and is able to determine a number of different compounds in a class simultaneously. In 1960, Vanden Heuvel and coworkers (1960) for the first time applied gas chromatography to the analysis of bile acids after converting them into methyl ester derivatives. Since then, gas chromatography has contributed greatly to the investigation of bile acid metabolism, analyzing bile acids in several biological samples such as bile, feces, serum, urine, gallstones or tissues.

Abbreviations: αα, 7α,12α-dihydroxy-5β-cholanoic acid; αβ, 7α,12β-dihydroxy-5β-cholanoic acid; βα, 7β,12α-dihydroxy-5β-cholanoic acid; ββ, 7β,12β-dihydroxy-5β-cholanoic acid; Glyco-αα, glyco-7α,12α-dihydroxy-5β-cholanoic acid; Glyco-αα 7-sulfate, glyco-7α,12α-dihydroxy-5β-cholanoic acid 7-sulfate; Glyco-βα 7-sulfate, glyco-7β,12α-dihydroxy-5β-cholanoic acid 7-sulfate; Tauro-αα, tauro-7α,12α-dihydroxy-5β-cholanoic acid; Tauro-αβ, tauro-7α,12β-dihydroxy-5β-cholanoic acid; Tauro-ββ, tauro-7β,12β-dihydroxy-5β-cholanoic acid

Metabolism and movement of bile acids

Bile acids in the human body are mainly composed of cholic acid, chenodeoxycholic acid, deoxycholic acid, lithocholic acid and ursodeoxycholic acid (Beppu et al., 1982; Yamaga et al., 1994a; Yamaga et al., 1996). Chenodeoxycholic acid and cholic acid are primary bile acids synthesized from cholesterol in the liver, and they are major catabolic products of cholesterol (Danielsson, 1973). Deoxycholic acid, lithocholic acid and ursodeoxycholic acid are secondary bile acids converted from primary bile acids by the action of intestinal flora (Hill and Drasar, 1968; Shimada et al., 1969; Aries and Hill, 1970). Most free bile acids are easily conjugated with glycine or taurine in the liver. Bile containing glycine- and taurine-conjugated bile acids is stored and concentrated in the gallbladder, and then released into the duodenum. Primary and secondary bile acids are absorbed almost exclusively from the ileum, return quantitatively to the liver by way of the portal circulation and are secreted into bile. This is called enterohepatic circulation of bile acids (Lack and Weiner, 1967; Dietschy, 1968; Dowling, 1972; Heaton, 1972). During enterohepatic circulation, some parts of bile acids are not absorbed to any significant extent from the intestine and excreted into feces (Eneroth et al., 1966; Dietschy, 1968; Tyor et al., 1971; Heaton, 1972). A part of bile acids leaks into the systemic circulation (van Berge-Henegouwen et al., 1974), and then excretes into the urine through the kidney.

Some parts of bile acids, especially secondary bile acids in the blood and urine are found as their sulfates (Palmer, 1967; Makino et al., 1973; Back, 1974), glucosides (Marschall et al., 1988; Marschall et al., 1989), glucuronides (Palmer,1967; Stiehl, 1974; Alme and Sjövall, 1980), and/or *N*-acetylglucosaminides (Marschall et al., 1988; Marschall et al., 1989; Takikawa et al., 1982; Yamaga et al., 1994a). The formation of unusual bile acids and the ratios of various conjugated bile acids offer useful information on hepatobiliary and gastrointestinal diseases (Garbutt et al., 1969; Neale et al., 1971; Takikawa et al., 1983a, 1983b).

Derivatizations of bile acids for gas chromatography

For gas chromatographic analysis the compounds analyzed are required to be volatile. Therefore, nonvolatile compounds should be converted into volatile derivatives quantitatively. It is true in the case of bile acids since they are polar compounds having a carboxyl group and some hydroxyl groups in their molecules. Usually, the carboxyl group of bile acids is methylated with diazomethane or hexafluoroisopropylated with hexafluoroisopropanol (Imai et al., 1976). The hydroxyl group is acetylated with acetic anhydride (Roovers et al., 1968) or trifluoroacetylated with trifluoroacetic anhydride (Endo et al., 1979). In addition, the hydroxyl group is silylated with both hexamethyldisilazane and trimethylchlorosilane (Makita and Wells, 1963), *N*-trimethylsilylimidazole (Karlangnis and Paumgartner, 1979; Amuro et al., 1983) or dimethylethylsilylimidazole (Miyazaki et al., 1977; Arimoto et al., 1982). In these situations, direct conversion of original conjugated bile acids into volatile derivatives has not been succeeded up to the present.

Fractionation and gas chromatographic analysis by difference in conjugated bile acid forms

As mentioned above, bile acids in human and animal bodies are present as a nonamidated form (free form) and forms conjugated with glycine, taurine, sulfuric acid, glucuronic acid and/or others. Therefore, in gas chromatographic analysis, bile acids must be converted into volatile derivatives after carrying out a number of complicated procedures. Bile acids extracted from an analytical sample are converted into free bile acids by solvolysis with hydrochloric acid (Back, 1937; van Berge-Henegowen et al., 1976; Alme et al., 1977; Yamaga et al., 1994a), followed by alkaline

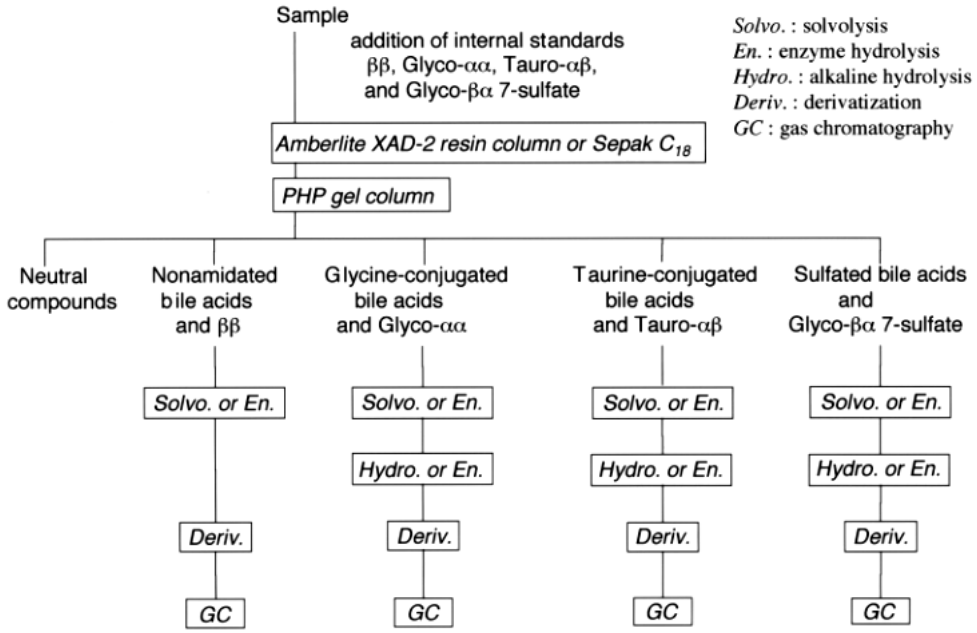

Fig. 1. Outline of procedures for systematic analysis of bile acids in a sample.

hydrolysis with 2 M sodium hydroxide solution (Nair and Garcia, 1969; Campbell et al., 1975; Yamaga et al., 1997) or enzymatic hydrolysis (Nair and Gordon, 1967; Cantafora et al., 1979), and free bile acids are converted into volatile derivatives. Bile acid derivatives are analyzed by gas chromatography.

However no information on the original conjugated forms of bile acids is obtained from the gas chromatogram. In order to solve this problem, crude bile acid extract from the analytical sample is first subjected to column chromatography with an ion exchange gel such as diethylaminohydroxypropyl-Sephadex-LH-20 (DEAP-LH-20) (Alme et al., 1977) or piperidinohydroxypropyl-Sephadex- LH-20 (PHP-LH-20) (Goto et al., 1978), fractionating into five fractions; each containing neutral compounds, nonamidated bile acids, glycine-conjugated bile acids, taurine-conjugated bile acids and sulfated bile acids. Each of all the fractions is subjected to solvolysis with hydrochloric acid, followed by hydrolysis with enzyme or 2 M sodium hydroxide solution, and then free bile acids thus obtained are converted into volatile derivatives for gas chromatographic analysis. Outline of common procedures for systematic analysis of bile acids in sample is shown in Fig. 1. By these procedures, the information on original conjugated bile acids is available.

Glucosides, glucuronides and *N*-acetylglucosaminides of bile acids (particular bile acid conjugates) are present in only their forms or double conjugated forms with glycine or taurine. When bile acid extract from biological sample was fractionated with PHP-LH-20 gel or DEAP-LH-20 gel column, these particular bile acid conjugates are not fractionated independently. No fractions are restricted where the particular bile acid conjugates are fractionated. For example, bile acid *N*-acetylglucosaminides are fractionated into both nonamidate fraction and glycine-conjugate fraction (Yamaga and Kohara, 1994). There are no reports describing the quantitative determination of bile acid glucosides, bile acid glucuronides and/or bile acid *N*-acetylglucosaminides in systematic analysis. The method for their analysis is referred to the individual reports (Takikawa et al., 1982; Marschall et al., 1988, 1989; Yamaga and Kohara, 1994).

Indispensability of internal standard compounds

A part of bile acids in an analytical sample, especially in a small volume sample, is certainly lost during procedures such as extraction, fractionation and other treatments. The usual method for correcting the loss of bile acids during analytical procedures is based on either adding an internal standard compound to the sample in the course of the systematic analysis (Fig. 1) or performing a recovery test using labeled and non-labeled bile acids under a condition similar to the analytical condition. For gas chromatographic analysis, the latter method does not ensure that the recovery from a biological sample will be the same as that from an artificial sample that has been prepared with labeled or non-labeled bile acids. Moreover, recovery may differ from assay to assay. Therefore, the use of internal standard compounds is entirely indispensable for correcting the loss of bile acids.

The minimum requirements for selecting internal standard compound for gas chromatography of bile acids

The minimum requirements for selecting a suitable internal standard compound for the determination of bile acids by gas chromatography are as follows.

i) Internal standard compound(s) must be added to the analytical sample before the extraction of bile acids. Then, the peak of characteristic internal standard compound must appear together with peaks of bile acids in the analytical sample on the same gas chromatogram.

ii) It is not necessary for internal standard compound(s) to be bile acid(s). However, it is better for them to be non-natural 5β-cholanoic acid homologues with some hydroxyl groups.

iii) Internal standard compound(s) should be stable. That is, during the analysis, they must not decompose to other compounds.

iv) After the fractionation with PHP-LH-20 gel column or DEAP-LH-20 gel column, the characteristic internal standard compound(s) should be transferred into each of all fractions. For this reason, four internal standard compounds consisting of non-amidated, glycine-conjugated, taurine-conjugated and sulfated forms, are necessary for the quantitative and qualitative determination of bile acids in each fraction after group separation.

v) The peak(s) of internal standard compound(s) must not pile up on the peaks of bile acids and the peaks of other mixed compounds in the biological sample.

vi) The retention time of the internal standard compound peak in each fraction must not be largely distant from those of bile acid peaks. Preferably, the peak of the internal standard compound should appear in the range between the first and the last bile acid peaks detectable on the gas chromatogram.

vii) Some linear relationship should be kept between the peak high or area and the weight of each bile acid to the internal standard compound.

When the selected internal standard compound(s) satisfy the requirements above mentioned, the area of an internal standard compound peak on the gas chromatogram is regarded as the amount (weight) of the internal standard compound added to the analytical sample, irrespective of the recovery rate during all the procedures. There is no occasion for considering the recovery ratio. It is only required to obtain linear calibration curves between the peak area ratios and the weight ratios of each bile acid to the internal standard compound.

Up to now, some kinds of unique bile acids such as 5β-cholanoic acid (Campbell et al., 1975),

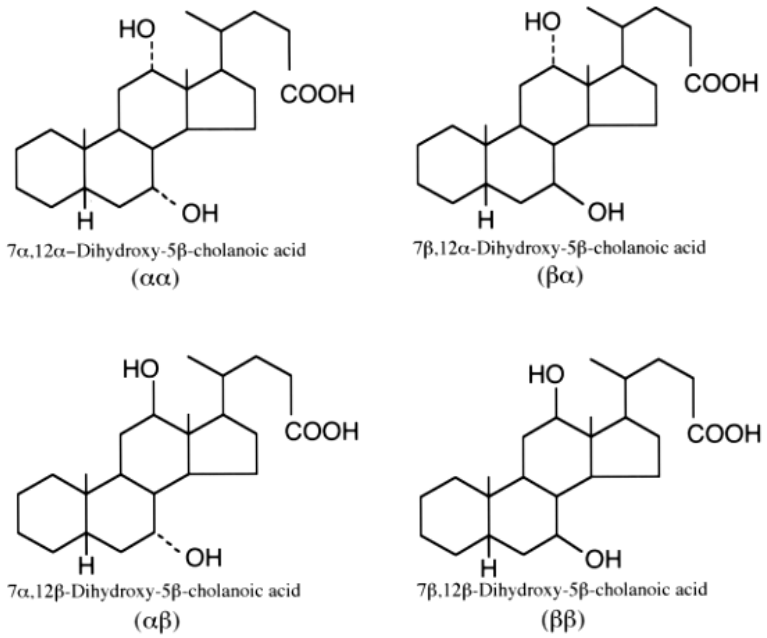

Fig. 2. Artificial bile acids chemically synthesized from cholic acid.

nordeoxycholic acid (van Berge-Henegouwen et al., 1977; Roda et al., 1978), hyodeoxycholic acid (Ali and Javitt, 1970; Karlangnis and Paumgartner, 1978; Cantafora et al., 1979), 7-ketolithocholic acid (Klaassen, 1971), 7-ketodeoxycholic acid (van Berge-Henegouwen et al., 1976) and hyocholic acid (Subbiah, 1973; Yamaga et al., 1983) have been used as an internal standard compound for gas chromatographic analysis. Certainly, these compounds are able to be used as an internal standard compound. But they have some drawbacks. They are sometimes found in samples from healthy subjects, neonates and some patients (Alme et al., 1977, 1978, 1980; Back and Walter, 1980; Sawada, 1981). Furthermore, oxo-5β-cholanoic acids such as 7-ketolithocholic acid and 7-ketodeoxycholic acid are easily vulnerable to decomposition during alkaline hydrolysis with sodium hydroxide solution (Lepase et al., 1978). For these reasons, it is necessary to develop other internal standard compounds.

Internal standard compounds for the determination of total bile acid amounts

Natural bile acids originally have a hydroxyl group at the C-3α position in the steroid nucleus. First, we chemically synthesized four isomers of 7,12-dihydroxy-5β-cholanoic acid lacking a hydroxyl group at C-3α position of cholic acid; 7α,12α-dihydroxy-5β-cholanoic acid (αα), 7β,12α-dihydroxy-5β-cholanoic acid (βα), 7α,12β-dihydroxy-5β-cholanoic acid (αβ) and 7β,12β-dihydroxy-5β-cholanoic acid (ββ) (Fig. 2) (Arimoto et al., 1982). An outline of the chemical synthesis of these artificial bile acids from cholic acid is shown in Fig. 3. These compounds in the derivatives of methyl ester dimethylethylsilyl (DMES) ether have different retention times compared to each other on the gas chromatogram (Fig. 4). In addition, the retention times of these four compounds are different from those of many authentic bile acids. But, only the retention time of αβ is very close to that of lithocholic acid (Table 1) and

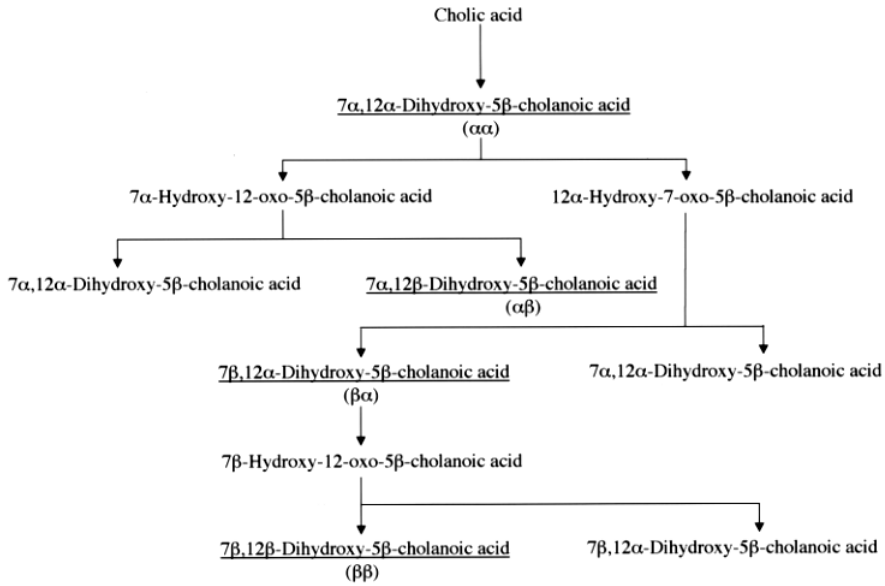

Fig. 3. Outline of chemical synthesis of four 7,12-dihydroxy-5β-cholanoic acid isomers from cholic acid.

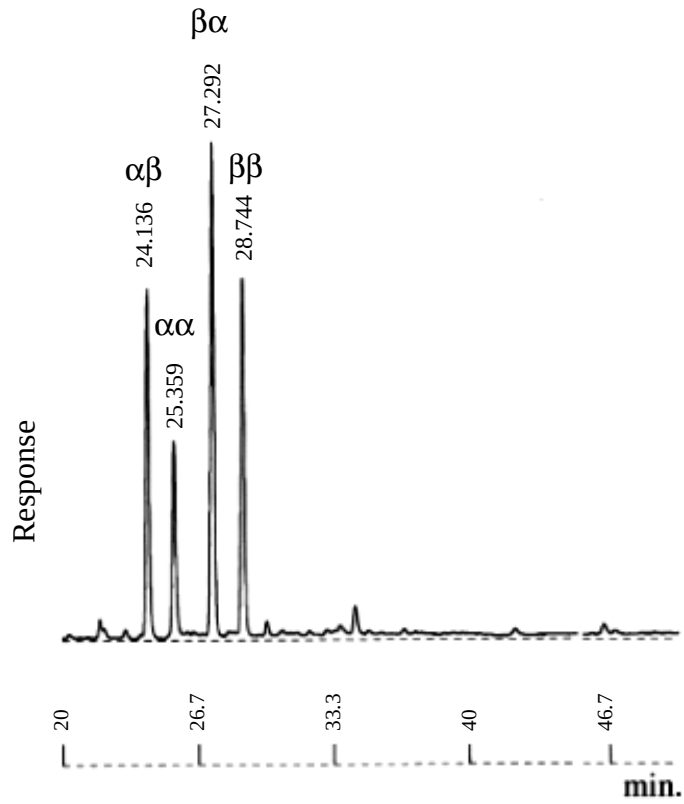

Fig. 4. Gas chromatogram of αα, αβ, βα and ββ (methyl ester DMES ether). (See Table 1 for gas chromatographic condition.)