Studies on the Constituents of Artemisia annua  
Part II

Tu You-you, Ni Mu-yun, Zhong Yu-rong, Li Lan-na, Cui Shu-lian, Zhang Mu-qun, Wang Xiu-zhen, Ji Zheng**  
and Liang Xiaotian**

* Institute of Chinese Materia Medica, Academy of Traditional Chinese Medicine, Beijing, China

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Abstract

The present paper is a continuation of our study on the Chinese traditional herb Artemisia annua L. [1—5], describing several additional constituents: qinghaosu IV and V (V, VII), qinghao acid (VIII) [6], chrysosplenol (VIa) [7] and a paraffinic alcohol; V, VII and VIII are compounds with unreported structures.

Introduction

A number of our earlier papers have been devoted to studies of chemical constituents isolated from Artemisia annua L. (Compositae), the most notable constituent being the antimalarial qinghaosu (I) [1—4], a peroxicid lactone with unique structure. Other constituents include qinghaosu-I-III (II-IV), a flavonol (VI), scopoletin and a few terpenes from the essential oil [5].

This paper deals with the isolation and characterization of V, VIa, VII, VIII and a paraffinic alcohol.

It is pertinent here to point out the close stereochemical kinship among the previously established structures I—IV. They all belong to the amorphane series (IX) [9], which has a cis decalin skeleton with the isopropyl group trans to the hydrogen on the ring juncture. Compounds I and IV are further distinguished by the presence of a modified seven-membered A-ring as the result of insertion of an extra ether oxygen.

1 For Part I, see ref. 5.
Results and Discussion

Qinghaosu-IV (V) is a colourless crystalline compound with m.p. 172—173°. MS molecular weight 282 (M⁺) agreed with C₁₅H₂₂O₅. Hydroxy and lactonic carbonyl groups can be inferred from its IR spectrum (3450, 1728 cm⁻¹). The ¹H NMR spectrum displayed the following features: δ 0.95 (d, J = 6 Hz, 10-CH₃), 1.20 (d, J = 6, 11-CH₃), 1.65 (s, 4-CH₃), 3.20 (m, H-C-11), 3.60 (br, H-C-3), 5.60 (s, H-C-5) and an exchangeable OH group at 1.88. Except for the two signals at δ 1.88 and 3.60, the NMR spectra of IV and V are almost superposable, thus leading to the conclusion that the extra oxygen of V is in the form of a hydroxy group with only four possible places (C-2, 3, 8 and 9) for its accommodation. Eu(fod) was used for its allocation. Addition of successive aliquots of the shift reagent gave rise to linear changes of chemical shifts. In the case of qinghaosu III (IV), we have for 10-CH₃, δ 0.95 — 0.96 — 1.16 — 1.16; for 11-CH₃, 1.20 — 1.42 — 2.20 — 2.40; for 4-CH₃, 1.54 — 1.55 — 1.74 — 1.75; and for H-C-5, 5.55 — 5.75 — 6.20 — 6.40. Qinghaosu IV (V) gave the corresponding shifts: 10-CH₃, δ 1.04 — 1.46 — 1.77 — 2.15; 11-CH₃, 1.27 — 1.99 — 2.60 — 3.42; 4-CH₃, 1.65 — 3.93 — 5.74 — 7.25; H-C-5, 5.70 — 6.91 — 8.06 — 9.18. The marked shifts for 4-CH₃ and H-C-5 in compound V is compatible only with an OH group at position-3, and the W½/6 Hz) of the H-C-3 multiplet (hence equatorial) indicates an α-orientation for the OH group (axial). The structure of IV has been firmly established by its preparation from qinghaosu (I) by catalytic hydrogenation [5].

Chrysosplenol (6a) has very similar UV and ¹H NMR spectra to eupatin (3, 5, 3'-triOH, 6, 7, 4'-triOMe) [7]. However, large discrepancies in m.p. of the acetates (155—157°; 219—221° for eupatin acetate) led us to a direct comparison of their IR spectra which also displayed conspicuous differences. The structure of chrysosplenol (VIa) was confirmed by the following facts. Methylation gave the hexamethyl ether, identical with an authentic specimen. The 5-OH showed a characteristic chelated NMR shift at δ 12.60. Methylation with CD₃N₂ in CH₃OH gave three partially deuterated methyl groups onto the original phenolic hydroxyls, and solvent shifts (benzene vs. chloroform [10]) revealed 5, 3' and 4' as the labelled positions. Further confirmation came from alkali fusion of the ethylated derivative, whereby 3,4-diethoxybenzoic acid (m.p. and MS) was obtained.

Qinghaosu acid (VIII) forms colourless cubes with m.p. 131°, [α]_D^20 +36° (0.01, CHCl₃) and MS m/e 234 (M⁺), compatible with C₁₅H₂₂O₅. IR peaks at 3480—2590 (s, br), 1690 (s) and 1625 (m) are indicative of an α, β-unsaturated acid. These are borne out by ¹H NMR data, δ 0.83 (d, J = 6, 10-CH₃), 1.60 (s, 4-CH₃), 4.94 (br, H-C-5), 5.54, 6.46 (br, 11 = CH₂) and 11.56 (br, CO₂H). Irradiation of 4-CH₃ caused an NOE increase of H-C-5 by 40%. No NOE was found between H-C-5 and the endocyclic methylene hydrogens, presumably due to free rotation of the C₇ — C₁ bond.

Comparison with II or its LAH reduction product (IIa) showed that the olefinic signal of qinghao acid at 4.94 (W½ = 5—6 Hz) is much sharper (for 2 and 2a, we have δ 5.60 and 5.50, respectively, with W½ = 11 Hz, due to the coupling with two neighboring protons). Hence the endocyclic double bond of qinghao acid should be placed at C₄ and not C₃, 4. Biogenetic considerations led to the proposal of VIII as the structure of qinghao acid.

Qinghaosu V (VII) has m.p. 125—126°, and a formula of C₁₅H₂₂O₅ from MS data. IR data (3420, 1700, 1630 cm⁻¹) showed the presence of OH and α, β-unsaturated lactone functionalities. The ¹H NMR spectrum showed two methyl groups at δ 0.85 (d) and 1.36 (s), and terminal methylene protons at 5.56 (s) and 16.16 (s). The carboxylic hydrogen at C-5 (δ 3.82) is a doublet with J = 3, hence should be in cis relationship with the hydrogen on the ring juncture (C-6). Further studies have been thwarted by scanty supply of material, and the structure as shown by VII is thus tentatively proposed, leaning heavily on biogenetic considerations.

We also isolated a straight chain fatty alcohol, m.p. 74—76°, characterized by its IR and ¹H NMR spectra. The MS peak at m/e 392 (M—18) [11] showed it to be octacosanol (C₂₈H₅₇OH), probably contaminated by some C₃₀ alcohol (ca. 5%) as evidenced by a tiny peak at m/e 420. Further fragmentations of interest involved successive losses of 28 units from m/e 392, giving peaks at m/e 364 and 336. The last mentioned peak however was stronger than usual [11], indicating the possible contamination by a C₂₆ alcohol. ULUBELEN et al. [12] reported the isolation of a C₂₆ alcohol from the same species, using elemental analysis as the main evidence. Since C₂₆ and C₂₈ alcohols cannot be adequately differentiated by elemental analysis, there is room for the possibility of their sample being also octacosanol.

Experimental

Melting points were not corrected. IR spectra were taken with KBr discs on an IR-S spectrometer. ¹H NMR spectra were taken with CDCl₃ solutions on WH-90, with TMS as the internal standard. MS were recorded with MM70—70H spectrometer.

Plant Material

Artemisia annua L. is a regular commodity, available in practically all warehouses for Chinese herbs. However, there might well be variations in chemical constituents with different localities, which were therefore specified below.

Silica gel columns and plates were used and eluted with the mixed solvent of petroleum ether and ethyl acetate in individually specified proportions.
Qinghaosu-IV

Plant material from Sichuan Province was extracted with petroleum ether and the solvent removed. The crude extract was chromatographed. Qinghaosu-IV displayed only a single spot on TLC (1:1 mixed solvent, 2% phosphomolybdic acid spray). It was purified by recrystallization from ethanol. MS, m/e (%): 282 (M⁺, 5), 238 (1), 222 (75), 207 (3), 204 (11), 194 (9), 178 (14), 166 (18), 150 (23), 137 (14), 122 (5), 107 (11), 93 (11), 81 (9), 74 (4), 69 (7), 55 (15), 43 (100). IR (cm⁻¹): 3450 (s), 2950 (m), 2870 (m), 1740 (s), 1450 (m), 1420 (s), 1380 (m), 1350 (m), 1274 (m), 1210 (s), 1185 (s), 1155 (m), 1110 (w), 1080 (m), 1050 (m), 1015 (m), 970 (m), 940 (w), 920 (m), 890 (m), 820 (m), 795 (w), 755 (w).

Qinghaosu acid

The crude acid displayed a single spot on TLC (9:1 mixed solvent, 2% vanillin-H₂SO₄ spray). It was purified by recrystallization from petroleum ether as transparent prisms, soluble in sodium bicarbonate. MS, m/e (%): 250 (M⁺, 24), 235 (7), 233 (6), 232 (15), 217 (7), 208 (18), 192 (18), 180 (15), 177 (10), 174 (8), 161 (11), 147 (15), 135 (10), 134 (12), 133 (13), 121 (15), 119 (15), 107 (26), 105 (19), 95 (37), 93 (27), 91 (31), 84 (13), 82 (23), 81 (28), 79 (28), 19 (77), 71 (35), 73 (25), 56 (10), 55 (32), 53 (30), 43 (100).

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Address: Prof. Liang Xiaotian, Institute of Materia Medica, Nan-nan Road, Beijing 100050, China.