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# Construction and analysis of acupoint network with functional similarity in Traditional Chinese Medicine
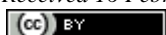
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**Abstract**

In this study, we constructed the data table of acupoint functions (i.e., acupoint indications and clinical applications) based on the previously developed information system of acupoint diagnosis and treatment in Traditional Chinese Medicine. Based on the data table of acupoint functions, between-acupoint point correlations were calculated. Acupoints with statistically significant point correlations were linked to construct the acupoint network with functional similarity. The degree centrality values of acupoints (totally 311 acupoints) showed that the acupoints Zhengying (GB17), Qinglengyuan (SJ11), Jiaji (EX-B2), etc. have the highest degree centrality values. Most of these acupoints are located on the head and neck, and their functions are universal. The acupoints Yinbai (SP1) and Zhongkui (EX-UE4) have strong specific functions and weak substitutability. The results of frequency distribution, skewness, aggregation index, coefficient of variation, entropy, and probability distributions showed that the obtained acupoint network is a scale-free complex network. Among them, the probability density function of the power law distribution is $p(x)=x^{-6.1818}$, $x \geq 36$.

**Keywords** acupoint network; acupoints; indications and clinical applications; functional similarity; point correlation; degree centrality; network topology; TCM.

## 1 Introduction

Acupoints are nodes inside meridians. According to the meridian theory of Traditional Chinese Medicine (TCM), meridians have five characteristics: (1) Meridians run the body's Qi and blood. (2) Meridians connect the internal organs of the human body. (3) Meridians cannot be seen directly with the naked eye. (4) Meridians conduct human diseases. (5) Meridians protect the internal organs of the human body. Meridian theory is a main part of the theoretical system of TCM (Zhang and Qi, 2023).

Meridians and acupoints form a biological network of matter, energy and information. The structure, function, dynamics and regulation of such a network follow the laws of network biology, and theory and methods of network biology can be used to analyze meridians and acupoints (Pujol et al., 2010; Ibrahim et al., 2011; Budvsky and Fraifeld, 2012; Li and Zhang, 2013; Rahman et al., 2013; Iqbal et al., 2014; Jesmin et al., 2016; Habib et al., 2016; Narad et al., 2017; Zhang and Feng, 2017; Banerjee, 2018; Benias et al., 2018; Zhang and Liu, 2019; Zhang and Zhang, 2019; Li et al., 2021; Xin and Zhang, 2020, 2021; Zhang, 2012a, 2016a-c, 2017a-d, 2018, 2021b; Lem et al., 2021; Yang and Zhang, 2022; Zhang and Qi, 2023).

Recently, we have developed the information system of acupoint diagnosis and treatment in TCM. In this system, we can choose to list the complete collection of TCM acupoint diagnosis and treatment information, or can search for TCM acupoint diagnosis and treatment information by keywords such as acupoint indications and clinical applications, acupoints, twelve meridians, eight extra meridians, and elements in Five Elements. In this study, we constructed the data table of acupoint functions (i.e., acupoint indications and clinical applications) based on the previously developed information system of acupoint diagnosis and treatment in TCM. Based on the data table of acupoint functions, between-acupoint point correlations were calculated and acupoints with statistically significant point correlations were linked to construct the acupoint network with functional similarity. And the network type and network topology were analyzed in order to provide a basis for further research.

## 2 Materials and Methods
### 2.1 Data sources
The data used to construct the acupoint network with functional similarity of TCM come from the information system of acupoint diagnosis and treatment in TCM (Zhang and Qi, 2023). We designed a simple Matlab program:

```
for i=1:651
func(:,i) = ~cellfun(@isempty, strfind(acufunctions,indicesfunctions{i}));
end
```

For each acupoint (311 acupoints in total), the 651 acupoint indications and clinical applications (referred to as acupoint functions thorought this study) were matched from the field of acupoint indications and clinical applications of the web database (Zhang and Qi, 2023). If there is a match, the corresponding function index of the acupoint is 1, otherwise it is 0. Thus, a 0-1 coding table with a size of 311×651 is generated, which is the data table of acupoint functions in this study.

### 2.2 Acupoint centrality
Degree centrality is used to measure the functional similarity between each acupoint and other acupoints in the network (Kuang and Zhang, 2011; Shams and Khansari, 2014; Jiang and Zhang, 2015; Zhang, 2012a, 2012c, 2016, 2018; Zhang and Zhang Zhan, 2011; Zhang and Feng, 2017; Zhang and Zhang, 2019; Xin and Zhang, 2020, 2021; Yang and Zhang, 2022). For a certain acupoint, the more other acupoints with the same functions, the greater the degree centrality value of this acupoint. For each acupoint, the total number of statistically significant acupoints associated with its point is the degree centrality of the acupoint.

### 2.3 Point correlation
Point correlation is a correlation measure of 0-1 data type variables (Zhang, 2012b, 2014, 2015, 2016, 2017b, 2018, 2021b; Zhang et al., 2014). Based on the data table of acupoint functions, between-acupoint point correlations were calculated according to the method of Zhang (2017b). The critical value of the statistical test

is set to *p*=0.00000001 (Zhang, 2022), and acupoint pairs of statistically significant point correlations were taken to construct the acupoint network with functional similarity in TCM.

## 2.4 Network construction

Based on the acupoint pairs of statistically significant point correlations, the paired acupoints were linked together one by one (Zhang, 2012b, 2016, 2018), and the acupoint network with functional similarity in TCM can be obtained. Animated human-machine interactive network were constructed by using online software (http://www.iaees.org/publications/software/netJa/netGen.htm) (Zhang, 2021a).

## 2.5 Network type

In this study, we use degree centrality, frequency distribution, skewness, aggregation index, coefficient of variation, entropy, binomial distribution, Poisson distribution, exponential distribution, power law distribution (Zhang and Liu, 2012; Zhang and Zhan, 2012; Zhang, 2012a, 2016, 2018; Zhang and Li, 2016), etc., to judge the network type obtained.

## 3 Results

### 3.1 Degree centrality of acupoints

The degree centrality values of acupoints are shown in Table 1. Table 1 shows that centrality values of acupoints Zhengying (GB17), Qinglengyuan (SJ11), Jiaji (EX-B2), Luxi (SJ19), Qingling (HT2), Shuaigu (GB8), Zuqiaoyin (GB44), Fengmen (BL12), Jayan (GB4), Xiaxi (GB43), Qiangjian (DU18), Shugu (BL65), Erjian (EX-HN6), Fubai ( GB10), Meichong (BL3), Yangxi (LI5), Fengfu (DU16), Wangu (GB12), etc., rank in the forefront. Most of these acupoints are located on the head and neck, and their functions are universal. Yinbai (SP1) and Zhongkui (EX-UE4) have strong specific functions and weak substitutability (see supplementary material).

**Table 1** Degree centrality values of all acupoints.

| Acupoint (穴位) | Degree centrality (度中心性) | Acupoint (穴位) | Degree centrality (度中心性) | Acupoint (穴位) | Degree centrality (度中心性) | Acupoint (穴位) | Degree centrality (度中心性) |
|---|---|---|---|---|---|---|---|
| 正营穴 (GB17) | 64 | 支正穴 (SI7) | 28 | 颊车穴 (ST6) | 15 | 腰俞穴 (DU2) | 9 |
| 清冷渊 (SJ11) | 62 | 臂臑穴 (LI14) | 27 | 鸠尾穴 (RN15) | 15 | 筑宾穴 (KI09) | 9 |
| 夹脊穴 (EX-B2) | 57 | 地机穴 (SP8) | 27 | 膀胱俞 (BL28) | 15 | 承山穴 (BL57) | 8 |
| 颅息穴 (SJ19) | 57 | 肩中俞 (SI15) | 27 | 通里穴 (HT5) | 15 | 鹤顶穴 (EX-LE2) | 8 |
| 青灵穴 (HT2) | 56 | 巨髎穴 (ST3) | 27 | 太白穴 (SP3) | 15 | 环跳穴 (GB30) | 8 |
| 率谷穴 (GB8) | 56 | 秉风穴 (SI12) | 26 | 膝阳关 (GB33) | 15 | 筋缩穴 (DU8) | 8 |
| 足窍阴 (GB44) | 53 | 关门穴 (ST22) | 26 | 小骨空 (EX-UE6) | 15 | 十宣穴 (EX-UE11) | 8 |
| 风门穴 (BL12) | 52 | 脾俞穴 (BL20) | 26 | 阳白穴 (GB14) | 15 | 神门穴 (HT7) | 8 |
| 颔厌穴 (GB4) | 52 | 府舍穴 (SP13) | 25 | 腰阳关 (DU3) | 15 | 阳陵泉 (GB34) | 8 |
| 侠溪穴 (GB43) | 49 | 膈俞穴 (BL17) | 25 | 华盖穴 (RN20) | 14 | 承筋穴 (BL56) | 7 |
| 强间穴 (DU18) | 48 | 天府穴 (LU3) | 25 | 髋骨穴 (EX-LE1) | 14 | 大椎穴 (DU14) | 7 |
| 束骨穴 (BL65) | 48 | 天泉穴 (PC2) | 25 | 日月穴 (GB24) | 14 | 胆俞穴 (BL19) | 7 |
| 耳尖穴 (EX-HN6) | 47 | 足临泣 (GB41) | 25 | 不容穴 (ST19) | 13 | 地五会 (GB42) | 7 |
| 浮白穴 (GB10) | 47 | 会宗穴 (SJ7) | 24 | 承泣穴 (ST1) | 13 | 会阴穴 (RN1) | 7 |
| 眉冲穴 (BL3) | 47 | 少海穴 (HT3) | 24 | 承灵穴 (GB18) | 13 | 箕门穴 (SP11) | 7 |
| 阳溪穴 (LI5) | 47 | 天窗穴 (SI16) | 24 | 兑端穴 (DU27) | 13 | 肩髃穴 (LI15) | 7 |
| 风府穴 (DU16) | 46 | 大横穴 (SP15) | 23 | 带脉穴 (GB26) | 13 | 脊中穴 (DU6) | 7 |
| 完骨穴 (GB12) | 45 | 耳门穴 (SJ21) | 23 | 伏兔穴 (ST32) | 13 | 厉兑穴 (ST45) | 7 |
| 金门穴 (BL63) | 44 | 气海穴 (RN6) | 23 | 魂门穴 (BL47) | 13 | 内关穴 (PC6) | 7 |

| | | | | | | |
|---|---|---|---|---|---|---|---|
| 至阴穴 (BL67) | 44 | 天柱穴 (BL10) | 23 | 肓门穴 (BL51) | 13 | 气舍穴 (ST11) | 7 |
| 当阳穴 (EX-HN2) | 43 | 听宫穴 (SI19) | 23 | 口禾髎 (LI19) | 13 | 曲池穴 (LI11) | 7 |
| 紫宫穴 (RN19) | 43 | 小肠俞 (BL27) | 23 | 太冲穴 (LR3) | 13 | 丘墟穴 (GB40) | 7 |
| 步廊穴 (KI22) | 42 | 陷谷穴 (ST43) | 23 | 温溜穴 (LI7) | 13 | 四缝穴 (Ex-UE10) | 7 |
| 解溪穴 (ST41) | 42 | 云门穴 (LU2) | 23 | 外丘穴 (GB36) | 13 | 肾俞穴 (BL23) | 7 |
| 神庭穴 (DU24) | 42 | 八风穴 (EX-LE10) | 22 | 胃仓穴 (BL50) | 13 | 天髎穴 (SJ15) | 7 |
| 悬厘穴 (GB6) | 42 | 攒竹穴 (BL2) | 22 | 殷门穴 (BL37) | 13 | 胃脘下俞 (EX-B3) | 7 |
| 跗阳穴 (BL59) | 41 | 大都穴 (SP2) | 22 | 中渚穴 (SJ3) | 13 | 阴包穴 (LR9) | 7 |
| 京骨穴 (BL64) | 40 | 大赫穴 (KI12) | 22 | 子宫穴 (EX-CA1) | 13 | 腰眼穴 (EX-B7) | 7 |
| 支沟穴 (SJ6) | 40 | 天突穴 (RN22) | 22 | 白环俞 (BL30) | 12 | 中枢穴 (DU7) | 7 |
| 库房穴 (ST14) | 39 | 交信穴 (KI8) | 21 | 冲阳穴 (ST42) | 12 | 章门穴 (LR13) | 7 |
| 彧中穴 (KI26) | 39 | 期门穴 (LR14) | 21 | 长强穴 (DU1) | 12 | 梁门穴 (ST21) | 6 |
| 大杼穴 (BL11) | 38 | 天枢穴 (ST25) | 21 | 大肠俞 (BL25) | 12 | 灵道穴 (HT4) | 6 |
| 丰隆穴 (ST40) | 38 | 瞳子髎 (GB1) | 21 | 大陵穴 (PC7) | 12 | 臑俞穴 (SI10) | 6 |
| 角孙穴 (SJ20) | 38 | 腹哀穴 (SP16) | 20 | 风市穴 (GB31) | 12 | 人迎穴 (ST9) | 6 |
| 神封穴 (KI23) | 38 | 合谷穴 (LI4) | 20 | 腹结穴 (SP14) | 12 | 三间穴 (LI3) | 6 |
| 玉枕穴 (BL9) | 38 | 曲差穴 (BL4) | 20 | 睛明穴 (BL1) | 12 | 委中穴 (BL40) | 6 |
| 液门穴 (SJ2) | 38 | 上巨虚 (S37) | 20 | 急脉穴 (LR12) | 12 | 承浆穴 (RN24) | 5 |
| 足通谷 (BL66) | 38 | 悬钟穴 (GB39) | 20 | 建里穴 (RN11) | 12 | 合阳穴 (BL55) | 5 |
| 中泉穴 (EX-UE3) | 38 | 鱼际穴 (LU10) | 20 | 阑尾穴 (EX-LE7) | 12 | 间使穴 (PC5) | 5 |
| 承光穴 (BL6) | 37 | 承满穴 (ST20) | 19 | 曲泽穴 (PC3) | 12 | 然谷穴 (KI2) | 5 |
| 肩贞穴 (SI9) | 37 | 公孙穴 (SP4) | 19 | 条口穴 (ST38) | 12 | 少府穴 (HT8) | 5 |
| 申脉穴 (BL62) | 37 | 少泽穴 (SI1) | 19 | 太溪穴 (KI3) | 12 | 天鼎穴 (LI17) | 5 |
| 耳和髎 (SJ22) | 36 | 天牖穴 (SJ16) | 19 | 心俞穴 (Bl15) | 12 | 阴郄穴 (HT6) | 5 |
| 灵墟穴 (KI24) | 36 | 足三里 (ST36) | 19 | 中脘穴 (RN12) | 12 | 督俞穴 (BL16) | 4 |
| 神藏穴 (KI25) | 36 | 至阳穴 (DU9) | 19 | 独阴穴 (EX-LE11) | 11 | 二白穴 (Ex-UE2) | 4 |
| 璇玑穴 (RN21) | 36 | 大包穴 (SP21) | 18 | 归来穴 (ST29) | 11 | 附分穴 (BL41) | 4 |
| 天宗穴 (SI11) | 35 | 光明穴 (GB37) | 18 | 肩髎穴 (SJ14) | 11 | 关冲穴 (SJ1) | 4 |
| 翳风穴 (SJ17) | 35 | 前顶穴 (DU21) | 18 | 巨阙穴 (RN14) | 11 | 关元穴 (RN4) | 4 |
| 周荣穴 (SP20) | 35 | 曲泉穴 (LR8) | 18 | 廉泉穴 (RN23) | 11 | 膈关穴 (BL46) | 4 |
| 水突穴 (ST10) | 34 | 阴陵泉 (SP9) | 18 | 灵台穴 (DU10) | 11 | 会阳穴 (BL35) | 4 |
| 外关穴 (SJ5) | 34 | 阳谷穴 (SI5) | 18 | 上脘穴 (RN13) | 11 | 极泉穴 (HT1) | 4 |
| 本神穴 (BG13) | 33 | 意舍穴 (BL49) | 18 | 腕骨穴 (SI4) | 11 | 肩前穴 (Ex-UE12) | 4 |
| 次髎穴 (BL32) | 33 | 腹通谷穴 (KI20) | 17 | 阴谷穴 (KI10) | 11 | 手三里 (LI10) | 4 |
| 昆仑穴 (BL60) | 33 | 肩外俞 (SI14) | 17 | 迎香穴 (LI20) | 11 | 素髎穴 (DU25) | 4 |
| 神堂穴 (BL44) | 33 | 列缺穴 (LU7) | 17 | 中冲穴 (PC9) | 11 | 小海穴 (SI8) | 4 |
| 陶道穴 (DU13) | 33 | 漏谷穴 (SP7) | 17 | 中渎穴 (GB32) | 11 | 水泉穴 (KI5) | 3 |
| 俞府穴 (KI27) | 33 | 三阴交 (SP6) | 17 | 髀关穴 (ST31) | 10 | 水沟穴 (DU26) | 3 |
| 八邪穴 (EX-UE9) | 32 | 手五里 (LI13) | 17 | 膻中穴 (RN17) | 10 | 委阳穴 (BL39) | 3 |
| 定喘穴 (EX-B1) | 32 | 太渊穴 (LU9) | 17 | 肺俞穴 (BL13) | 10 | 照海穴 (KI6) | 3 |
| 风池穴 (GB20) | 32 | 涌泉穴 (KI1) | 17 | 关元俞 (BL26) | 10 | 志室穴 (BL52) | 3 |
| 膏肓穴 (BL43) | 32 | 地仓穴 (ST4) | 16 | 后溪穴 (SI3) | 10 | 百虫窝 (EX-LE3) | 2 |
| 孔最穴 (LU6) | 32 | 大迎穴 (ST5) | 16 | 金津玉液 (EX-HN12) | 10 | 二间穴 (LI2) | 2 |
| 侠白穴 (LU4) | 32 | 经渠穴 (LU8) | 16 | 命门穴 (DU4) | 10 | 巨骨穴 (LI16) | 2 |
| 尺泽穴 (LU5) | 31 | 厥阴俞 (BL14) | 16 | 胞肓穴 (BL53) | 9 | 内踝尖 (EX-LE8) | 2 |
| 瘈脉穴 (SJ18) | 31 | 肩井穴 (GB21) | 16 | 冲门穴 (SP12) | 9 | 外踝尖 (Ex-LE9) | 2 |
| 横骨穴 (KI11) | 31 | 居髎穴 (GB29) | 16 | 大敦穴 (LR1) | 9 | 血海穴 (SP10) | 2 |
| 颈百劳 (Ex-HN23) | 31 | 蠡沟穴 (LR5) | 16 | 犊鼻穴 (ST35) | 9 | 养老穴 (SI6) | 2 |
| 外陵穴 (ST26) | 31 | 内庭穴 (ST44) | 16 | 大骨空 (EX-UE5) | 9 | 承扶穴 (BL36) | 1 |
| 印堂穴 (DU29) | 31 | 气冲穴 (ST30) | 16 | 复溜穴 (KI7) | 9 | 大钟穴 (KI4) | 1 |

| 飞扬穴 (BL58) | 30 | 颧髎穴 (SI18) | 16 | 肝俞穴 (BL18) | 9 | 梁丘穴 (ST34) | 1 |
| 缺盆穴 (ST12) | 30 | 少商穴 (LU11) | 16 | 后顶穴 (DU19) | 9 | 落枕穴 (EX-UE8) | 1 |
| 身柱穴 (DU12) | 30 | 神阙穴 (RN8) | 16 | 滑肉门穴 (ST24) | 9 | 气端穴 (EX-LE12) | 1 |
| 阳辅穴 (GB38) | 30 | 上廉穴 (LI9) | 16 | 聚泉穴 (EX-HN10) | 9 | 神道穴 (DU11) | 1 |
| 百会穴 (DU20) | 29 | 胃俞穴 (BL21) | 16 | 少冲穴 (HT9) | 9 | 阴市穴 (ST33) | 1 |
| 肓俞穴 (KI16) | 29 | 阳池穴 (SJ4) | 16 | 三焦俞 (BL22) | 9 | 膝眼穴 (EX-LE5) | 0 |
| 哑门穴 (DU15) | 29 | 扶突穴 (LI18) | 15 | 上髎穴 (BL31) | 9 | 隐白穴 (SP1) | 0 |
| 大巨穴 (ST27) | 28 | 浮郄穴 (BL38) | 15 | 石门穴 (RN5) | 9 | 中魁穴 (EX-UE4) | 0 |
| 中府穴 (LU1) | 28 | 京门穴 (GB25) | 15 | 五处穴 (BL5) | 9 | | |

### 3.2 Point correlation

After comprehensive weighing, the critical value for statistical test is set to $p=0.00000001$ (Zhang, 2022). Calculate between-acupoint point correlations and 2953 pairs of acupoints with statistically significant point correlations were obtained (see supplementary material for full list: http://www.iaees.org/publications/journals/nb/articles/2023-13(3)/e-suppl/Zhang-Supplementary-Material.rar). Table 2 lists the acupoints with the top three degree centrality values.

**Table 2** Acupoint pairs with statistically significant point correlations ($p=0.00000001$, $n=651$; a total of 2953 pairs of acupoints, only the significant point correlations for the top three acupoints are listed).

| Acupoint (穴位) | Acupoint (穴位) | Point Corr. (点相关) | Acupoint (穴位) | Acupoint (穴位) | Point Corr. (点相关) | Acupoint (穴位) | Acupoint (穴位) | Point Corr. (点相关) |
|---|---|---|---|---|---|---|---|---|
| 正营穴 (GB17) | 百会穴 (DU20) | 0.2594 | 清冷渊 (SJ11) | 臂臑穴 (LI14) | 0.3481 | 夹脊穴 (EX-B2) | 臂臑穴 (LI14) | 0.3096 |
| 正营穴 (GB17) | 本神穴 (BG13) | 0.4103 | 清冷渊 (SJ11) | 百会穴 (DU20) | 0.2594 | 夹脊穴 (EX-B2) | 百会穴 (DU20) | 0.3508 |
| 正营穴 (GB17) | 八邪穴 (EX-UE9) | 0.4957 | 清冷渊 (SJ11) | 本神穴 (BG13) | 0.2698 | 夹脊穴 (EX-B2) | 本神穴 (BG13) | 0.3648 |
| 正营穴 (GB17) | 八风穴 (EX-LE10) | 0.5265 | 清冷渊 (SJ11) | 八邪穴 (EX-UE9) | 0.4957 | 夹脊穴 (EX-B2) | 八邪穴 (EX-UE9) | 0.291 |
| 正营穴 (GB17) | 攒竹穴 (BL2) | 0.2336 | 清冷渊 (SJ11) | 八风穴 (EX-LE10) | 0.3481 | 夹脊穴 (EX-B2) | 八风穴 (EX-LE10) | 0.3096 |
| 正营穴 (GB17) | 承光穴 (BL6) | 0.4103 | 清冷渊 (SJ11) | 攒竹穴 (BL2) | 0.2336 | 夹脊穴 (EX-B2) | 承光穴 (BL6) | 0.239 |
| 正营穴 (GB17) | 瘛脉穴 (SJ18) | 0.2815 | 清冷渊 (SJ11) | 承光穴 (BL6) | 0.2698 | 夹脊穴 (EX-B2) | 瘛脉穴 (SJ18) | 0.2496 |
| 正营穴 (GB17) | 大杼穴 (BL11) | 0.2594 | 清冷渊 (SJ11) | 瘛脉穴 (SJ18) | 0.2815 | 夹脊穴 (EX-B2) | 大杼穴 (BL11) | 0.2295 |
| 正营穴 (GB17) | 当阳穴 (EX-HN2) | 0.2815 | 清冷渊 (SJ11) | 大杼穴 (BL11) | 0.2594 | 夹脊穴 (EX-B2) | 当阳穴 (EX-HN2) | 0.2496 |
| 正营穴 (GB17) | 耳尖穴 (EX-HN6) | 0.373 | 清冷渊 (SJ11) | 当阳穴 (EX-HN2) | 0.2815 | 夹脊穴 (EX-B2) | 耳尖穴 (EX-HN6) | 0.332 |
| 正营穴 (GB17) | 耳和髎 (SJ22) | 0.3098 | 清冷渊 (SJ11) | 耳尖穴 (EX-HN6) | 0.373 | 夹脊穴 (EX-B2) | 耳和髎 (SJ22) | 0.2752 |
| 正营穴 (GB17) | 丰隆穴 (ST40) | 0.2698 | 清冷渊 (SJ11) | 耳和髎 (SJ22) | 0.3098 | 夹脊穴 (EX-B2) | 丰隆穴 (ST40) | 0.3648 |
| 正营穴 (GB17) | 风门穴 (BL12) | 0.4434 | 清冷渊 (SJ11) | 丰隆穴 (ST40) | 0.2698 | 夹脊穴 (EX-B2) | 风门穴 (BL12) | 0.3954 |
| 正营穴 (GB17) | 风府穴 (DU16) | 0.3098 | 清冷渊 (SJ11) | 风门穴 (BL12) | 0.4434 | 夹脊穴 (EX-B2) | 风府穴 (DU16) | 0.2752 |
| 正营穴 (GB17) | 飞扬穴 (BL58) | 0.4697 | 清冷渊 (SJ11) | 风府穴 (DU16) | 0.3098 | 夹脊穴 (EX-B2) | 风池穴 (GB20) | 0.2629 |
| 正营穴 (GB17) | 浮白穴 (GB10) | 0.2815 | 清冷渊 (SJ11) | 飞扬穴 (BL58) | 0.3098 | 夹脊穴 (EX-B2) | 飞扬穴 (BL58) | 0.2752 |
| 正营穴 (GB17) | 跗阳穴 (BL59) | 0.3098 | 清冷渊 (SJ11) | 浮白穴 (GB10) | 0.2815 | 夹脊穴 (EX-B2) | 浮白穴 (GB10) | 0.2496 |
| 正营穴 (GB17) | 光明穴 (GB37) | 0.2947 | 清冷渊 (SJ11) | 跗阳穴 (BL59) | 0.3098 | 夹脊穴 (EX-B2) | 跗阳穴 (BL59) | 0.2752 |
| 正营穴 (GB17) | 颔厌穴 (GB4) | 0.381 | 清冷渊 (SJ11) | 关冲穴 (SJ1) | 0.274 | 夹脊穴 (EX-B2) | 关冲穴 (SJ1) | 0.2415 |
| 正营穴 (GB17) | 金门穴 (BL63) | 0.373 | 清冷渊 (SJ11) | 光明穴 (GB37) | 0.4472 | 夹脊穴 (EX-B2) | 光明穴 (GB37) | 0.2615 |
| 正营穴 (GB17) | 京骨穴 (BL64) | 0.3481 | 清冷渊 (SJ11) | 颔厌穴 (GB4) | 0.25 | 夹脊穴 (EX-B2) | 金门穴 (BL63) | 0.332 |
| 正营穴 (GB17) | 解溪穴 (ST41) | 0.3481 | 清冷渊 (SJ11) | 金门穴 (BL63) | 0.373 | 夹脊穴 (EX-B2) | 京骨穴 (BL64) | 0.4693 |
| 正营穴 (GB17) | 肩贞穴 (SI9) | 0.2815 | 清冷渊 (SJ11) | 京骨穴 (BL64) | 0.3481 | 夹脊穴 (EX-B2) | 解溪穴 (ST41) | 0.3096 |
| 正营穴 (GB17) | 角孙穴 (SJ20) | 0.3274 | 清冷渊 (SJ11) | 解溪穴 (ST41) | 0.3481 | 夹脊穴 (EX-B2) | 肩贞穴 (SI9) | 0.3804 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 正营穴 (GB17) | 夹脊穴 (EX-B2) | 0.4434 | 清冷渊 (SJ11) | 肩贞穴 (SI9) | 0.2815 | 夹脊穴 (EX-B2) | 肩髃穴 (LI15) | 0.2752 |
| 正营穴 (GB17) | 孔最穴 (LU6) | 0.2414 | 清冷渊 (SJ11) | 角孙穴 (SJ20) | 0.3274 | 夹脊穴 (EX-B2) | 角孙穴 (SJ20) | 0.291 |
| 正营穴 (GB17) | 昆仑穴 (BL60) | 0.4472 | 清冷渊 (SJ11) | 夹脊穴 (EX-B2) | 0.4434 | | | |
| 正营穴 (GB17) | 列缺穴 (LU7) | 0.25 | 清冷渊 (SJ11) | 孔最穴 (LU6) | 0.2414 | | | |
| 正营穴 (GB17) | 颅息穴 (SJ19) | 0.373 | 清冷渊 (SJ11) | 昆仑穴 (BL60) | 0.2947 | | | |
| 正营穴 (GB17) | 眉冲穴 (BL3) | 0.373 | 清冷渊 (SJ11) | 列缺穴 (LU7) | 0.381 | | | |
| 正营穴 (GB17) | 清冷渊 (SJ11) | 0.4969 | 清冷渊 (SJ11) | 颅息穴 (SJ19) | 0.373 | | | |
| 正营穴 (GB17) | 强间穴 (DU18) | 0.5636 | 清冷渊 (SJ11) | 眉冲穴 (BL3) | 0.373 | | | |
| 正营穴 (GB17) | 青灵穴 (HT2) | 0.4434 | | | | | | |
| 正营穴 (GB17) | 少海穴 (HT3) | 0.2265 | | | | | | |
| 正营穴 (GB17) | 少泽穴 (SI1) | 0.2947 | | | | | | |
| 正营穴 (GB17) | 神庭穴 (DU24) | 0.3481 | | | | | | |
| 正营穴 (GB17) | 上廉穴 (LI9) | 0.2947 | | | | | | |
| 正营穴 (GB17) | 率谷穴 (GB8) | 0.3274 | | | | | | |
| 正营穴 (GB17) | 束骨穴 (BL65) | 0.4697 | | | | | | |
| 正营穴 (GB17) | 申脉穴 (BL62) | 0.2947 | | | | | | |
| 正营穴 (GB17) | 天柱穴 (BL10) | 0.381 | | | | | | |
| 正营穴 (GB17) | 陶道穴 (DU13) | 0.2698 | | | | | | |
| 正营穴 (GB17) | 天牖穴 (SJ16) | 0.3098 | | | | | | |
| 正营穴 (GB17) | 外关穴 (SJ5) | 0.2265 | | | | | | |
| 正营穴 (GB17) | 完骨穴 (GB12) | 0.2594 | | | | | | |
| 正营穴 (GB17) | 外踝尖 (Ex-LE9) | 0.2454 | | | | | | |
| 正营穴 (GB17) | 悬钟穴 (GB39) | 0.2265 | | | | | | |
| 正营穴 (GB17) | 悬厘穴 (GB6) | 0.2947 | | | | | | |
| 正营穴 (GB17) | 侠溪穴 (GB43) | 0.2815 | | | | | | |
| 正营穴 (GB17) | 玉枕穴 (BL9) | 0.5265 | | | | | | |
| 正营穴 (GB17) | 阳溪穴 (LI5) | 0.2414 | | | | | | |
| 正营穴 (GB17) | 阳辅穴 (GB38) | 0.3098 | | | | | | |
| 正营穴 (GB17) | 翳风穴 (SJ17) | 0.3367 | | | | | | |
| 正营穴 (GB17) | 印堂穴 (DU29) | 0.25 | | | | | | |
| 正营穴 (GB17) | 哑门穴 (DU15) | 0.2698 | | | | | | |
| 正营穴 (GB17) | 液门穴 (SJ2) | 0.2594 | | | | | | |
| 正营穴 (GB17) | 中渚穴 (SJ3) | 0.25 | | | | | | |
| 正营穴 (GB17) | 足临泣 (GB41) | 0.3277 | | | | | | |
| 正营穴 (GB17) | 足窍阴 (GB44) | 0.2265 | | | | | | |
| 正营穴 (GB17) | 足通谷 (BL66) | 0.373 | | | | | | |
| 正营穴 (GB17) | 支沟穴 (SJ6) | 0.2815 | | | | | | |
| 正营穴 (GB17) | 支正穴 (SI7) | 0.4103 | | | | | | |
| 正营穴 (GB17) | 至阴穴 (BL67) | 0.4038 | | | | | | |

### 3.3 Acupoint network with functional similarity in Traditional Chinese Medicine

Link the acupoints with statistically significant point correlations to obtain the acupoint network with functional similarity in TCM. The animated human-machine interactive network constructed by online software (Zhang, 2021a; see supplementary material also) is shown in Fig. 1. The interactive animation can be viewed by opening the homepage in a web browser (http://www.iaees.org/publications/journals/nb/articles/2023-13(3)/e-suppl/AcupointFuncNetwork.html). In the animation, press and hold the target acupoint and drag to observe other acupoints of strong functional

similarity with this acupoint (Zhang, 2021a). Generally speaking, the stronger the similarity between the functions of B and A, the fewer the shortest links from B to A, and the greater the motion amplitude of B when dragging A.
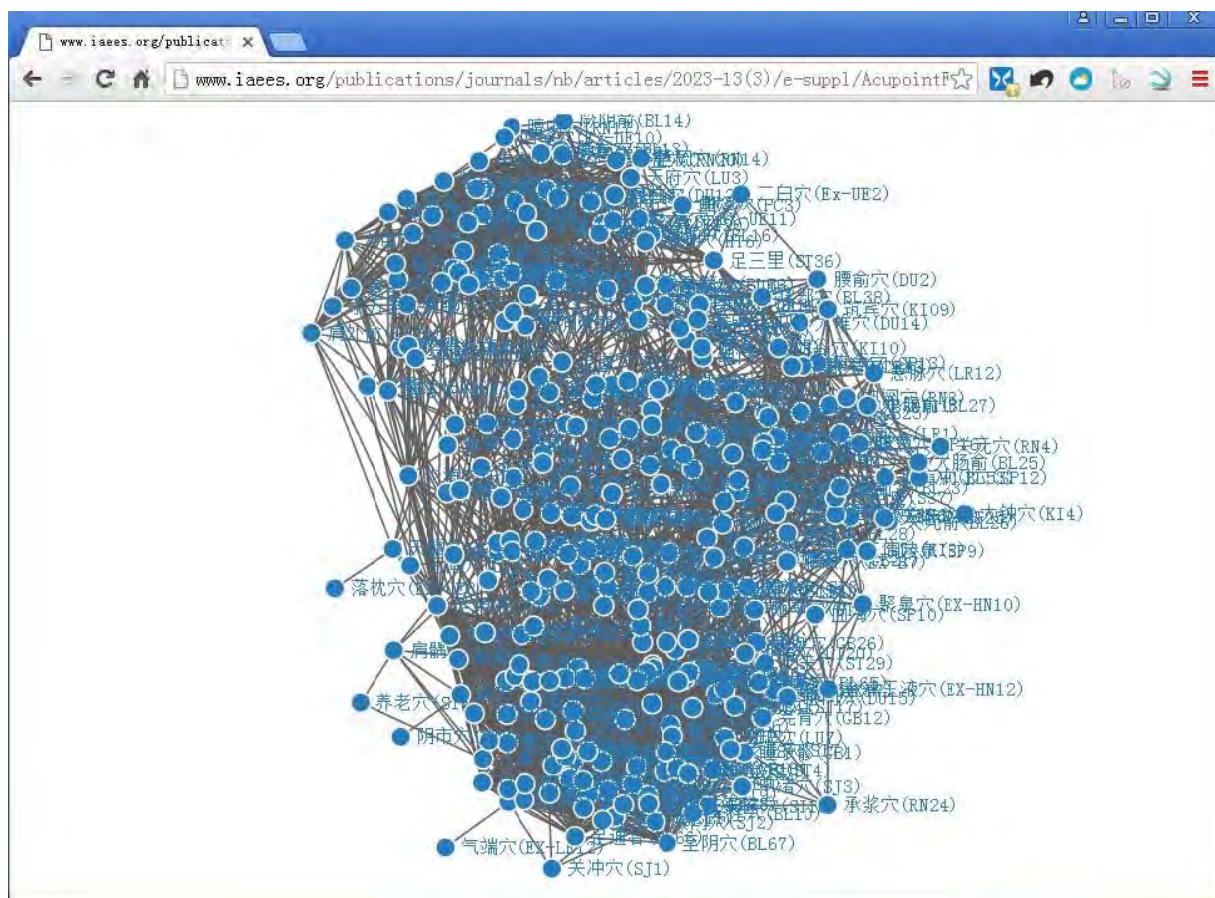


**Fig. 1** The homepage of the acupoint network with functional similarity in TCM. Press and hold the target acupoint and drag to observe other acupoints of strong functional similarity with this acupoint (http://www.iaees.org/publications/journals/nb/articles/2023-13(3)/e-suppl/AcupointFuncNetwork.html).

### 3.4 Network type
(1) Skewness of acupoints' degree distribution and network's aggregation index

The skewness of acupoints' degree distribution=0.073395 (≠0), and the network's aggregation index is 1.4674 (>1), therefore the network tends to be a complex network.

(2) Network's coefficient of variation and entropy

Network's variation coefficient $H$=9.9023 (>1), network entropy $E$=169.0579, therefore the network tends to be a complex network.

(3) Frequency distribution of degree centrality values

The frequency distribution of degree centrality values of the network is shown in Table 3. It can be seen from the table that the frequency distribution is highly asymmetric. The proportion of acupoints with low degree is obviously dominant, and the proportion of acupoints with high degree is very small. The network tends to be non-random.

**Table 3** Frequency distribution of acupoints' degree centrality in the network.

| Avg. degr | 3.2 | 9.6 | 16 | 22.4 | 28.8 | 35.2 | 41.6 | 48 | 54.4 | 60.8 |
|---|---|---|---|---|---|---|---|---|---|---|
| Freq. | 0.1511 | 0.2572 | 0.2154 | 0.0997 | 0.0739 | 0.0997 | 0.045 | 0.0289 | 0.0225 | 0.0032 |

(4) Probability distribution of degree centrality values

Binomial distribution parameters $p$=0.2737, $\chi^2$ =184.6788, the network tends to be a non-random network.

Poisson distribution parameters $\lambda$=18.9904, $\chi^2$ =1255570792.8868, the network tends to be a non-random network.

Exponential distribution parameters $\lambda$=0.0527, $\chi^2$ =71.7152, the network is not an exponential distribution network.

Power law distribution parameters $\alpha$=6.1818, $x_{min}$=36; its probability density function is $p(x)=x^{-6.1818}$, $x \geq 36$; Kolmogorov-Smirnov goodness of fit $D$=0.1153. The degree centrality values are distributed in a power law, and the network is a scale-free complex network.

In general, the acupoint network with functional similarity in TCM is a scale-free complex network.

**4 Discussion**

The acupoint network in this study is based on the acupoints' functional similarity of TCM. For acupoint A, if acupoint B has more of the same functions (i.e., acupoint indications and clinical applications) as acupoint A, that is, the greater the similarity of functions, then the point correlation between acupoint A and acupoint B is stronger, and the possibility of being a network link is greater. Therefore, the acupoint network of functional similarity in TCM reflects the similarity of acupoint functions. For acupoint A, the more other acupoints with the same function, the greater the degree centrality value of acupoint A. Therefore, the degree centrality value based on functional similarity does not represent the importance of acupoints, but the universality of acupoint functions. For example, Zusanli (ST36), Guanyuan (RN4), Yongquan (KI1), Dazhui (DU14), etc., are all one of the most important acupoints in the human body, but their degree centrality values based on their functional similarity is not large. If it is necessary to construct a network based on the importance of acupoints, we should select relevant attributes reflecting the importance of acupoints, and use the same method to construct the network.

**References**

Banerjee S. 2018. A bioinformatics and network analysis framework to find novel therapeutics for autoimmunity. Network Biology, 8(1): 44-54

Benias PC, Wells RG, Sackey-Aboagye B. et al. 2018. Structure and distribution of an unrecognized interstitium in human tissues. Scientific Report, 8: 4947

Habib N, Ahmed K, Jabin I, Rahman MM. 2016. Application of R to investigate common gene regulatory network pathway among bipolar disorder and associate diseases. Network Biology, 6(4): 86-100

Ibrahim SS, Eldeeb MAR, Rady MAH. 2011. The role of protein interaction domains in the human cancer network. Network Biology, 1(1): 59-71

Iqbal S, Ejaz H, Nawaz MS, et al. 2014. Meta-analysis of cancer transcriptomes: A new approach to uncover molecular pathological events in different cancer tissues. Network Biology, 4(1): 1-20

Jesmin T, Waheed S, Al-Emran A. 2016. Investigation of common disease regulatory network for metabolic

disorders: A bioinformatics approach. Network Biology, 6(1): 28-36

Jiang LQ, Zhang WJ. 2015. Determination of keystone species in CSM food web: A topological analysis of network structure. Network Biology, 5(1): 13-33

Kuang WP, Zhang WJ. 2011. Some effects of parasitism on food web structure: a topological analysis. Network Biology, 1(3-4): 171-185

Lem FF, Opook F, Lawson FP, et al. 2021. Network pharmacology and component analysis of four herbs decoction molecular mechanism in hypertension treatment. Network Biology, 11(2): 54-67

Li JR, Zhang WJ. 2013. Identification of crucial metabolites/reactions in tumor signaling networks. Network Biology, 3(4): 121-132

Li TJ, Tang BQ, Zhang WB, et al. 2021. In vivo visualization of the pericardium meridian with fluorescent dyes. Evidence-Based Complementary and Alternative Medicine, 2021: Article ID 5581227

Narad P, Upadhyaya KC, Som A. 2017. Reconstruction, visualization and explorative analysis of human pluripotency network. Network Biology, 7(3): 57-75

Pujol A, Mosca R, Farres J, et al. 2010. Unveiling the role of network and systems biology in drug discovery. Trends in Pharmacological Sciences, 31: 115-123

Rahman KMT, Md. Islam F, Banik RS, et al. 2013. Changes in protein interaction networks between normal and cancer conditions: Total chaos or ordered disorder? Network Biology, 3(1): 15-28

Shams B, Khansari M. 2014. Using network properties to evaluate targeted immunization algorithms. Network Biology, 4(3): 74-94

Xin SH, Zhang WJ. 2020. Construction and analysis of the protein-protein interaction network for the olfactory system of the silkworm *Bombyx mori*. Archives of Insect Biochemistry and Physiology, 105(3): e21737

Xin SH, Zhang WJ. 2021. Construction and analysis of the protein-protein interaction network for the detoxification enzymes of the silkworm, *Bombyx mori*. Archives of Insect Biochemistry and Physiology, 108(4): e21850

Yang S, Zhang WJ. 2022. Systematic analysis of olfactory protein-protein interactions network of fruitfly, *Drosophila melanogaster*. Archives of Insect Biochemistry and Physiology, 110(2): e21882

Zhang GL, Zhang WJ. 2019. Protein-protein interaction network analysis of insecticide resistance molecular mechanism in *Drosophila melanogaster*. Archives of Insect Biochemistry and Physiology, 100(1): e21523

Zhang WJ. 2012a. Computational Ecology: Graphs, Networks and Agent-based Modeling. World Scientific, Singapore

Zhang WJ. 2012b. How to construct the statistic network? An association network of herbaceous plants constructed from field sampling. Network Biology, 2(2): 57-68

Zhang WJ. 2012c. Several mathematical methods for identifying crucial nodes in networks. Network Biology, 2(4): 121-126

Zhang WJ. 2014. Interspecific associations and community structure: A local survey and analysis in a grass community. Selforganizology, 1(2): 89-129

Zhang WJ, Wang R, Zhang DL, et al. 2014. Interspecific associations of weed species around rice fields in Pearl River Delta, China: A regional survey. Selforganizology, 1(3-4): 143-205

Zhang WJ. 2015. Calculation and statistic test of partial correlation of general correlation measures. Selforganizology, 2(4): 65-77

Zhang WJ. 2016. Selforganizology: The Science of Self-Organization. World Scientific, Singapore

Zhang WJ. 2017a. Network pharmacology of medicinal attributes and functions of Chinese herbal medicines: (I) Basic statistics of medicinal attributes and functions for more than 1100 Chinese herbal medicines.

Network Pharmacology, 2(2): 17-37. http://www.iaees.org/publications/journals/np/articles/2017-2(2)/basic-statistics-of-medicinal-attributes-and-functions.pdf

Zhang WJ. 2017b. Network pharmacology of medicinal attributes and functions of Chinese herbal medicines: (II) Relational networks and pharmacological mechanisms of medicinal attributes and functions of Chinese herbal medicines. Network Pharmacology, 2(2): 38-66. http://www.iaees.org/publications/journals/np/articles/2017-2(2)/networks-and-mechanisms-of-medicinal-attributes-and-functions.pdf

Zhang WJ. 2017c. Network pharmacology of medicinal attributes and functions of Chinese herbal medicines: (IV) Classification and network analysis of medicinal functions of Chinese herbal medicines. Network Pharmacology, 2(3): 82-104. http://www.iaees.org/publications/journals/np/articles/2017-2(3)/classification-and-network-analysis-of-medicinal-functions.pdf

Zhang WJ. 2017d. Network pharmacology of medicinal attributes and functions of Chinese herbal medicines: (III) Canonical correlation functions between attribute classes and linear eignmodels of Chinese herbal medicines. Network Pharmacology, 2(3): 67-81. http://www.iaees.org/publications/journals/np/articles/2017-2(3)/canonical-correlation-functions-between-attribute-classes.pdf

Zhang WJ. 2018. Fundamentals of Network Biology. World Scientific Europe, London, UK

Zhang WJ. 2021a. A web tool for generating user-interface interactive networks. Network Biology, 11(4): 247-262. http://www.iaees.org/publications/journals/nb/articles/2021-11(4)/web-tool-for-generating-user-interface-interactive-networks.pdf

Zhang WJ. 2021b. Construction and analysis of the word network based on the Random Reading Frame (RRF) method. Network Biology, 11(3): 154-193

Zhang WJ. 2022. $p$-value based statistical significance tests: Concepts, misuses, critiques, solutions and beyond. Computational Ecology and Software, 12(3): 80-122

Zhang WJ, Qi YH. 2023. Information system of acupoint diagnosis and treatment in Traditional Chinese Medicine. Network Biology, 13(2): 53-73. http://www.iaees.org/publications/journals/nb/articles/2023-13(2)/information-system-of-acupoint-diagnosis-and-treatment.pdf

Zhang WJ, Feng YT. 2017. Metabolic pathway of non-alcoholic fatty liver disease: Network properties and robustness. Network Pharmacology, 2(1): 1-12

Zhang WJ, Li X. 2016. Generate networks with power-law and exponential-law distributed degrees: with applications in link prediction of tumor pathways. Network Pharmacology, 1(1): 15-35

Zhang WJ, Liu GH. 2012. Creating real network with expected degree distribution: A statistical simulation. Network Biology, 2(3): 110-117

Zhang WJ, Liu GH. 2019. Naturalness and preference for species selection of Chinese medicinal seed plants. Network Pharmacology, 4(1-2): 1-5. http://www.iaees.org/publications/journals/np/articles/2019-4(1-2)/naturalness-and-preference-for-species-selection-of-Chinese-medicinal-plants.pdf

Zhang WJ, Zhan CY. 2011. An algorithm for calculation of degree distribution and detection of network type: with application in food webs. Network Biology, 1(3-4): 159-170