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Usefulness of 2D fusion of postmortem CT and antemortem chest radiography studies for human identification

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Conflict of Interest

The authors declare that they have no conflict of interest.

Ethical Statement

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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Abstract

Purpose To determine the feasibility of human identification by the two-dimensional (2D) fusion of postmortem computed tomography (PMCT)- and antemortem chest radiography.

Materials and Methods The study population consisted of 15 subjects who had undergone chest radiography studies more than 12 months before death. These and PMCT images were fused using a workstation, and the minimum-distance gap between anatomical landmarks on images obtained with the two modalities was calculated. In each case the mean-distance gap (MDG) was recorded as the mean of all minimum-distance gaps. The anatomical landmarks were placed at soft tissue- and in bone sites. The MDG was compared in the same- and different subjects.

Results The MDG of the evaluation sites was significantly smaller when the fused images were from the same- rather than a different subject ($p < 0.01$). For the bone landmarks, the same subject was identified as the first candidate in 33.3%, the 1st or 2nd candidate in 73.3% and the 1st to 3rd candidate in 86.7% of the comparisons. Bone- were superior to soft-tissue landmarks for the establishment of the candidate order ($p < 0.05$).

Conclusion The 2D fusion of antemortem chest radiography- and postmortem CT images may assist in human identification.

Keywords: Identification; 2D fusion; antemortem chest radiography; postmortem CT

Introduction

Postmortem computed tomography (PMCT) is useful to detect the cause of death such as lethal hemorrhagic lesions, bone lesions, gas, liquid, foreign bodies, and so on. PMCT scans are performed to screen for the cause of death as an alternative to autopsy, or adjunct to autopsy, and to determine whether autopsy is required [1].

Human identification has been performed mainly based on DNA profiling, fingerprinting, dental X-ray and facial features. Recently radiologic features such as medical devices [2], aortic plaques [3], paranasal sinus morphology [3,4], cranial suture patterns [5], dental images [6], clavicles [7], thoracic vertebras [8], bone trabecular patterns [9] are used for human identification.

Chest radiography studies are widely used to diagnose chest diseases and for medical checkups and cancer screening in certain countries including Japan. Therefore, chest radiography can be a common antemortem medical imaging.

Under the hypothesis that the comparison of antemortem chest radiography- and PMCT images is useful for the human identification, we fused these images to identify the subject from whom the two sets of images were obtained. The purpose of our study was to verify the hypothesis that the comparison of antemortem chest radiography- and PMCT images is useful for the human identification.

Materials and methods

Subjects

This retrospective study was approved by our institutional review board; the requirement for informed consent was waived. Among 82 subjects who underwent PMCT studies at our institute between April 2010 and February 2014, we enrolled 15 (11 men, 4 women; aged 20 to 90 years, mean 65 ± 19 years) who had undergone chest radiography examinations more than 12 months prior to their death (Table. 1). The time period between the antemortem chest radiography and the PMCT was 372 to 4949 days, mean 1397± 1180 days. The time period between death and the PMCT was 29 to 359 minutes, mean 114 ± 94 minutes. Cases with chest trauma were not included in this study.

Chest radiography and CT acquisition

In 13 subjects a digital X-ray system (RADREX-i, Toshiba Medical Systems) was used. The conditions were upright position, postero-anterior projection, 120 kV, 200 mA, and source-to-image receptor distance (SID) 2 m. In 2 subjects the antemortem chest radiography studies were performed on a portable computed radiography (CR) system (Mobile Art Lumina, Shimadzu Medical Systems Corp., Osaka, Japan). The conditions were supine and antero-posterior projection, 120 kV, 250 mA, and 1 m SID.

For PMCT of 14 subjects we used a 64-detector row scanner (SOMATOM Definition AS+, Siemens Medical, Erlangen, Germany), 120 kVp. and automatic exposure control (AEC). PMCT of one subject was on a 4-detector row scanner (Aquilion TSX-101A/4A, Toshiba Medical Systems, Ohtawara, Japan) at 120 kVp and 300 mA. The PMCT image data consisted of 5-mm axial sections through the thoracic region.

2D Fusion of antemortem- and postmortem studies

Image analysis was performed using a 2D fusion module on a workstation (Vincent Ver.4, Fuji Film Medical Systems, Tokyo, Japan). PMCT data were reconstructed into chest radiography-like RaySum images using the same workstation.

Two radiologists independently placed anatomical landmarks on the reconstructed RaySum images and the antemortem chest radiography. The observers were cognizant of the subjects' gender, age, and cause of death.

The 2D fusion module automatically placed a minimum distance between corresponding anatomical landmarks on the fused images. For each anatomical landmark a minimum-distance gap (mm) was automatically calculated and then the mean-distance gap, defined as the mean of all minimum distance gaps, was calculated. In mean-distance gaps measured by the 2 observers, the smaller value was used for final measurement of them.

The algorithm used for fusion was landmark-based registration [10]. Landmark-based registration and methods derived therefrom are widely used in for clinical positron-emission tomography (PET)-, CT-, and magnetic resonance imaging (MRI) studies [11]. Although 3D- and 3D images are often fused, we used 2D antemortem chest radiography-and 3D postmortem CT images. Therefore, we needed to manually adjust the orientation of the reconstructed images.

Assessment based on soft tissues (Experiment 1)

For each comparison the observers chose 5 soft tissue sites, i.e. the bilateral pulmonary apices, the carina, and the bilateral most distal edges of the thoracic cavity at the level of the carina. These sites were easily recognized on RaySum- reconstructed from PMCT- and antemortem chest radiography images. In the anatomical landmarks, the bilateral pulmonary apices and the carina were used for 3-point method, the bilateral pulmonary apices and the bilateral most distal edges of the thoracic cavity at the level of the carina for 4-point method, and all 5 of these landmarks for 5-point method (Fig. 1). On fused images displayed on the workstation, the mean-distance gap (mm) was automatically calculated. Approximately 60 sec were required to create the fusion images. For each comparison study we used 15 fused images of the same subject and 210 (15×14) fused images of different subjects. A total of 675 fused images were created [(210 + 15) x 3] for assessments based on soft tissues.

Assessment based on bones (Experiment 2)

For these investigations the observers identified the dorsal parts of the 3rd and 4th ribs at the midline of the bilateral bony thorax (Fig. 1). On RaySum- reconstructed from PMCT- and antemortem chest radiography, these sites were chosen because they were more easily detected than the spine and sternum and because on chest radiography studies, breathing had less effect on the upper part of the thorax. The mean-distance gap (mm) was automatically calculated on the workstation. The observers evaluated a total of 225 fused images; 15 from the same subject and 210 (15x14) from of different subjects.

Image analysis

We hypothesized that the mean-distance gap on fusion images was shorter for the same- than different subjects. We used the smallest mean-distance gap to identify the first candidate for being the same subject, the second smallest mean-distance gap for identifying the second candidate, etc. Thus, we determined the candidate order based on the size of the mean-distance gap.

Statistical analysis

For each assessment, interobserver agreement was assessed with the intraclass correlation coefficient (ICC), in which ICC < 0.40 = poor, 0.40–0.59 = fair, 0.60–0.74 = good, and ICC > 0.74 = excellent.[12)] Group analysis between the same and different subjects was performed with the Mann-Whitney *U*-test. The statistical significance of the mean difference in the order of candidates for being the same subject was assessed with the Wilcoxon signed-rank test. All statistical analyses were with commercial software (Statistical Package for the Social Sciences, Version 23, SPSS, Chicago, Illinois; MedCalc for Windows, MedCalc Software, Mariakerke, Belgium). Differences of $p < 0.05$ were considered statistically significant.

Results

Assessment based on soft tissue (Experiment 1)

The ICC with a 95% confidence interval for interobserver agreement on 3-, 4-, and 5-point methods was excellent; it was 0.991 with 0.9879–0.9928 for 3-point method, 0.999 with 0.9989–0.9994 for 4-point method and 0.998 with 0.9973–0.9984 for 5-point method.

When we used 3 soft-tissue sites, the mean-distance gap ± standard deviation (SD) was 4.13 ± 2.99 mm for the same- and 5.61 ± 3.08 mm for different subjects. The difference was not statistically significant. With 4 sites, the mean-distance gap was 4.01 ± 2.24 mm for the same- and 6.47 ± 2.96 mm for different subjects ($p < 0.01$) and with 5 sites it was 4.70 ± 2.57 mm and 6.77 ± 2.73 mm, respectively ($p < 0.01$) (Fig. 2).

With 3 sites, the same subject was identified as the 1st candidate in 20.0%-, and as the 1st or 2nd-, the 1st to 3rd-, and as the 1st to 4th candidate in 40.0% of the comparisons (Fig. 3a). With 4 sites the same subject was identified as the 1st candidate in 13.3%-, as the 1st or 2nd candidate in 53.3%, as the 1st to 3rd candidate in 60.0%, and as the 1st to 4th candidate in 66.7% of the comparisons (Fig. 3b). Using 5 sites, the same subject was identified as the 1st candidate in 33.3%-, as the 1st or 2nd candidate in

46.7%-, as the 1st to 3rd candidate in 66.7%-, and as the 1st to 4th candidate in 66.7% of the comparisons (Fig. 3c).

Assessment based on bones (Experiment 2)

The ICC with a 95% confidence interval for interobserver agreement was excellent; it was 0.993 with 0.9910–0.9946. The mean-distance gap was 0.82 ± 0.30 mm for the same subject and 1.83 ± 0.81 mm for different subjects ($p < 0.01$) (Fig. 4). The same subject was identified as the 1st candidate in 33.3%-, as the 1st or 2nd candidate in 73.3%-, as the 1st to 3rd candidate in 86.7%-, and as the 1st to 4th candidate in 100% of the comparisons (Fig. 3d). With respect to the candidate order, assessment based on bones was significantly superior to soft-tissue comparisons irrespective of the number of soft-tissue sites evaluated ($p < 0.05$) (Fig. 5).

Discussion

Our findings indicate that 2D fusion of antemortem chest radiography and postmortem CT images renders subject identification possible. We found that when comparisons were based on 4 or 5 soft-tissue sites, and when anatomical landmarks were used for bone-based comparisons, there were significant differences in the mean-distance gap between the same and different subjects. The bone-based was better than the soft-tissue-based method for establishing the candidate order, probably because bone tends to be less affected by the cause of death, the postmortem time lapse, and postmortem decomposition changes.

Some radiographic features are useful for human identification. Pfaeffli et al. [13] compared antemortem radiographs and PMCT images of the frontal sinus and pelvis. Their identification relies on visual morphological matching and is qualitative. We, on the other hand, compared antemortem radiographs with PMCT scans. This facilitated quantitative assessments using readily-available antemortem data. To our knowledge, we are first to report this identification method. Compared with the previous method using antemortem radiographs and PMCT images of the frontal sinus and pelvis, our method using antemortem chest radiographs may be easier for obtaining antemortem X-ray data.

Although our technique may be less accurate than DNA, fingerprint and dental X-ray data, it may be useful for the following situations. In some subjects, it might be difficult to obtain antemortem DNA. Postmortem fingerprint may not be taken due to skin injury such as burn. When a subject had severe head and neck injury, antemortem dental X-ray may not be helpful for human identification. In such situations, our technique may be useful for narrowing down identification of an individual from among several candidates. This is particularly important when the casualty number is high. The consensual selection of anatomical landmarks on 2D fusion images by our two radiologists required 1 to 2 minutes. The development of a computer system and special software for the automatic selection and comparison of anatomical landmarks is desirable.

Our study has some limitations. First, we only used specific bones as anatomical landmarks. Although the sternum, spinal column, and other bones are present in the chest region, it can be difficult to clearly identify the sternum and spinal column on radiographs even after adjusting the window level and width. Second, the CT slice thickness was relatively thick (5 mm). The use of thin-slice original images would render the placement of anatomical landmarks more accurate. Third, for antemortem chest radiographic- and PMCT studies, the body position and respiratory status were different. Fourth, cases with chest trauma were not included in this study. In cases of incident or mass disaster with several victims, thoracic trauma can be present. In such situations, this current technique may not be useful for human identification. Fifth, our data were obtained from a single-center study in a small number of patients. Additional studies with large populations are needed.

Conclusion

The 2D fusion of antemortem chest radiography- and postmortem CT images may assist in human identification; bones are better landmarks than soft tissues.

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Figure Legends

Figure 1

Placement of anatomical landmarks on antemortem chest radiography- (left upper, white squares) and RaySum images (left lower, white circles) reconstructed from postmortem CT (PMCT) scans.

a-c Soft-tissue assessment with (a) 3 sites, (b) 4 sites, (c) 5 sites. The anatomical landmarks were placed on the bilateral pulmonary apices, the carina, and/or the bilateral most distal edges of the thoracic cavity at the level of the carina.

d Bone assessment. The anatomical landmarks were the dorsal part of the 3rd and 4th ribs at the midline of the bilateral bony thorax.

The 2D fusion module automatically set a minimum distance between corresponding anatomical landmarks on the fused images (right, white squares and circles). In each session, the mean-distance gap, defined as the mean of all minimum-distance gaps was calculated.

Figure 2

Soft-tissue assessment (experiment 1). Comparison of the mean-distance gaps (mm) between the same and different subjects using 3 (left), 4 (center), and 5 sites (right). When 4 or 5 sites were used, the difference in the mean-distance gaps between the same- and different subjects was statistically significant ($p < 0.01$).

Figure 3

The candidate order based on the size of the mean-distance gap.

a-c Soft-tissue assessments (experiment 1) with (a) 3 sites, (b) 4 sites, (c) 5 sites

d Bone assessments (experiment 2)

Black circle and white diamond identify the same- and other subjects, respectively. We considered the images with the smallest mean-distance gap to be the 1st candidate for the identification of the same subject.

With 3 sites (a), 3 of 15 subjects (20%, cases 2,4,8) were the 1st candidates for identity, 6 (40%, cases 2,3,4,7,8,15) were 2nd-, 3rd-, and 4th candidates. Using 4 sites (b), 2 subjects (13.3%, cases 2 and 8) were the 1st candidates, 8 (53.3%, cases 1,2,4,7,8,9,13,15) were 2nd-, 9 (60%, cases 1,2,4,5,7,8,9,13,15) were 3rd-, and 10 (66.7%, cases 1,2,4,5,7,8,9,11,13,15) were the 4th candidates. When we used 5 sites (c) we found that 5 subjects (33.3%, cases 2,4,8,9,15) were 1st-, 7 (46.7%, cases 2,4,8,9,12,13,15) were 2nd-, and 10 (67%, cases 1,2,4,5,7,8,9,12,13,15) were 3rd or 4th candidates for identity.

In bone assessment studies (d), 5 of 15 subjects (33.3%, cases 3,4,5,8,15) were the 1st candidates for identity, 11 (73.3%, cases 1-5,8,10-13,15) were the 2nd-,13 (86.7%, cases 1-5,7-13,15) the 3rd-, and all 15 subjects the 4th candidates.

Figure 4

Bone assessments (experiment 2). Comparison of the mean-distance gaps (mm) between identical- and different subjects revealed a significant difference ($p < 0.01$).

Figure 5

Comparison of the candidate order between the soft-tissue assessments (experiment 1) with (a) 3 sites, (b) 4 sites and (c) 5 sites and the bone assessments (experiment 2). For all comparisons, there was a significant difference between the results obtained with the two experiments ($p < 0.05$).

Table

Table 1

Summary of subject's characteristics

Number of case	Age/sex	Time period between the antemortem chest X-ray and the PMCT (days)	Time period between death and the PMCT (minutes)	Cause of death
1	87/M	571	79	Acute cardiac failure
2	74/F	479	262	Acute cardiac failure
3	70/M	2475	59	Aspiration pneumonia
4	83/M	4949	29	Unknown
5	71/M	372	48	Pulmonary embolism
6	83/F	932	60	Drowning, Cerebral hemorrhage
7	35/F	1065	68	Shock(cause unknown)
8	90/M	1478	91	Acute cardiac failure
9	54/M	855	56	Acute cardiac failure
10	77/M	1082	359	Unknown
11	53/M	2547	150	Gastric cancer
12	21/M	1653	47	Acute cardiac failure
13	59/M	1015	154	Lung cancer
14	56/M	592	193	Acute myeloid leukemia
15	68/F	886	50	Acute aortic dissection

Note. M, male; F, female; PMCT, postmortem computed tomography

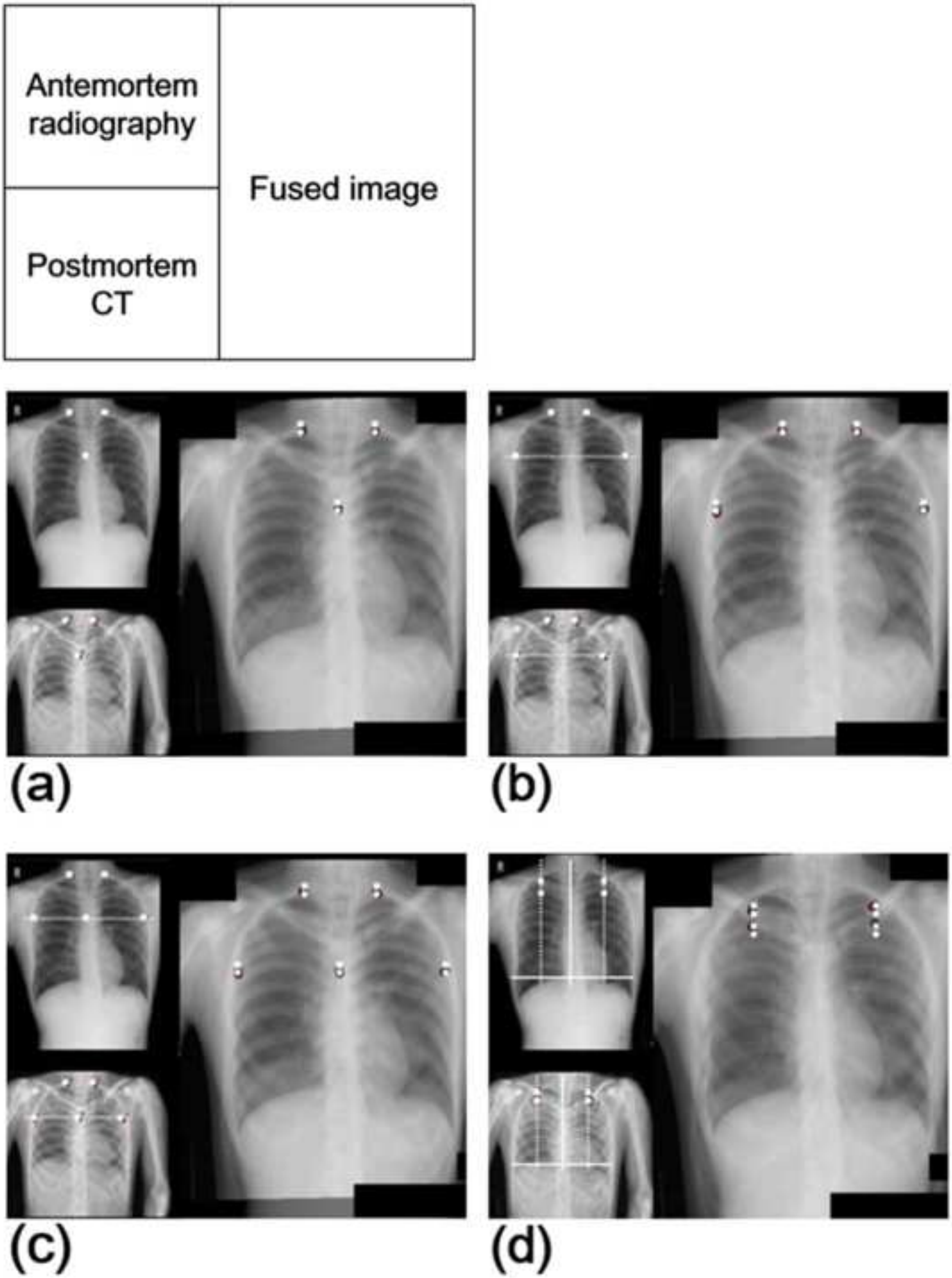
Antemortem radiography
Postmortem CT
Fused image
(a)
(b)
(c)
(d)

Fig.2

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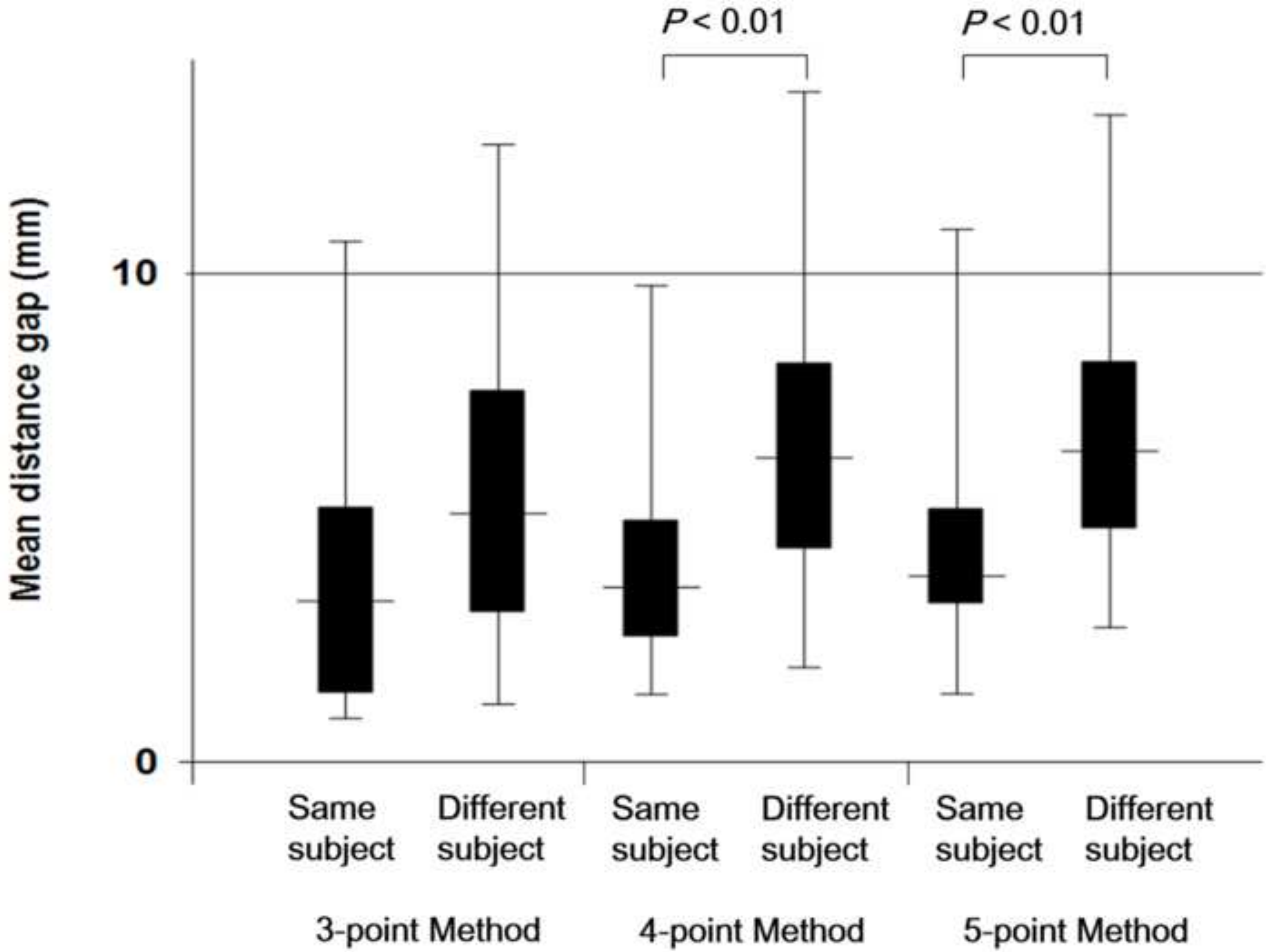

Fig.3a

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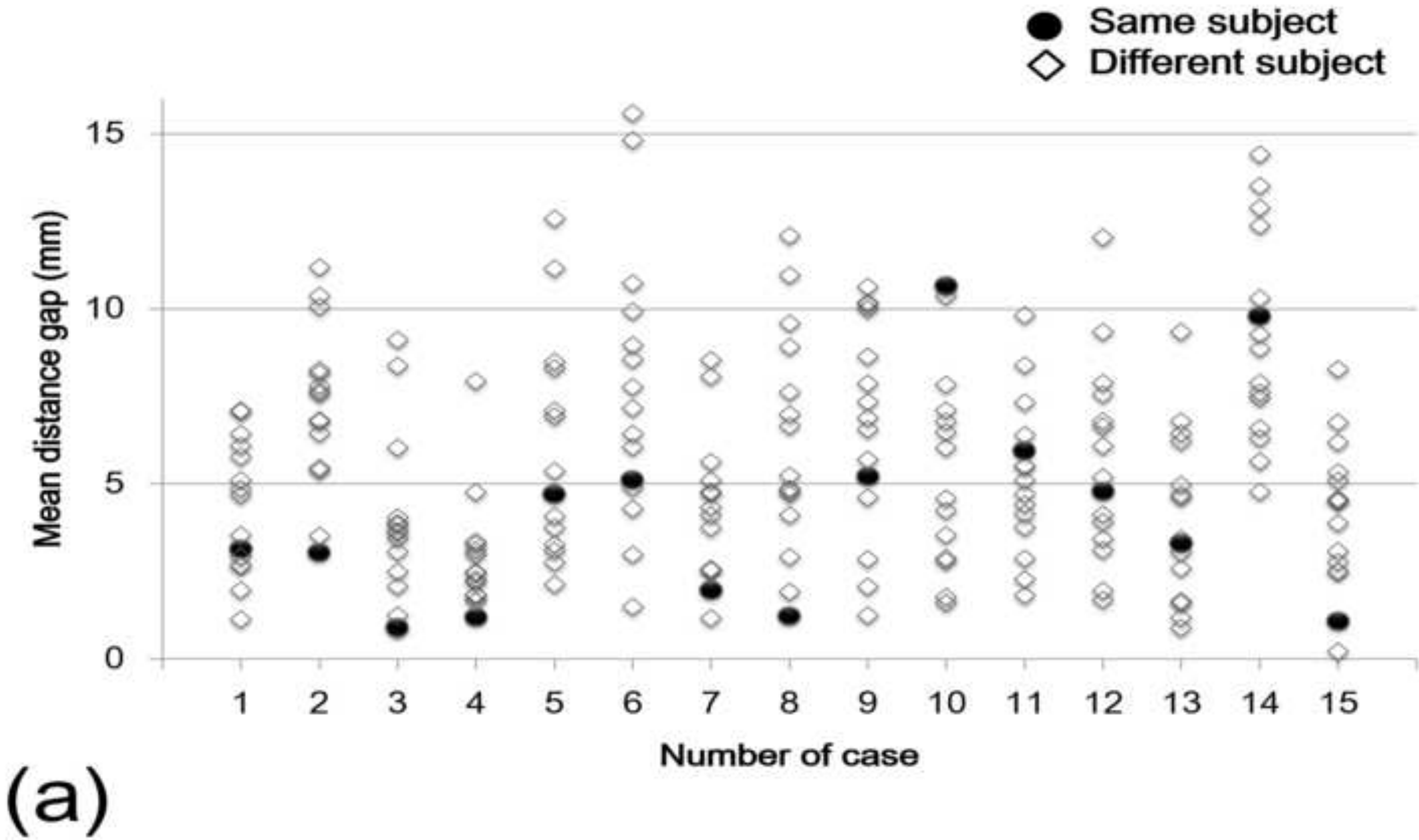
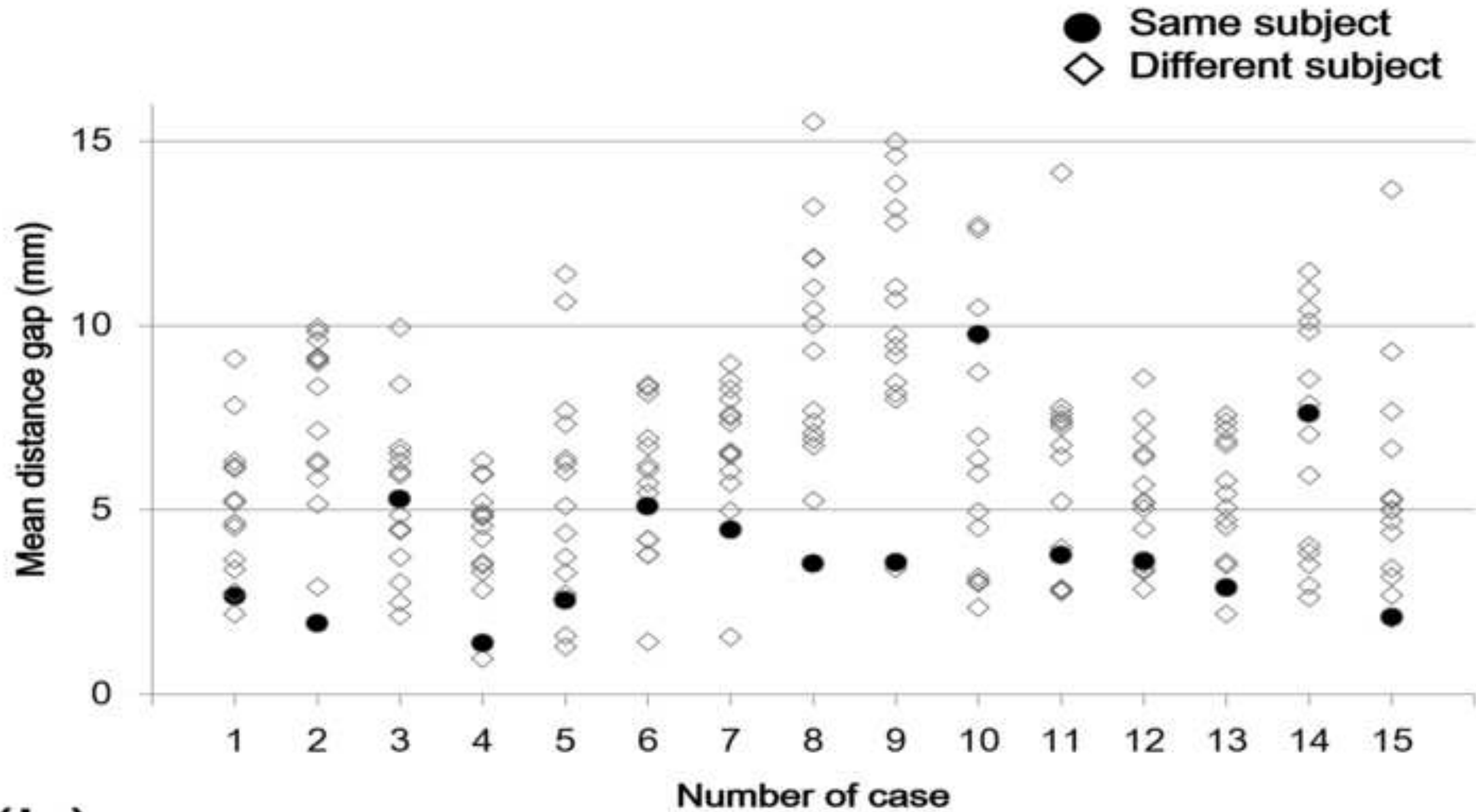


Fig.3b


Same subject
Different subject
Mean distance gap (mm)
15
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Number of case

(b)

Fig.3c

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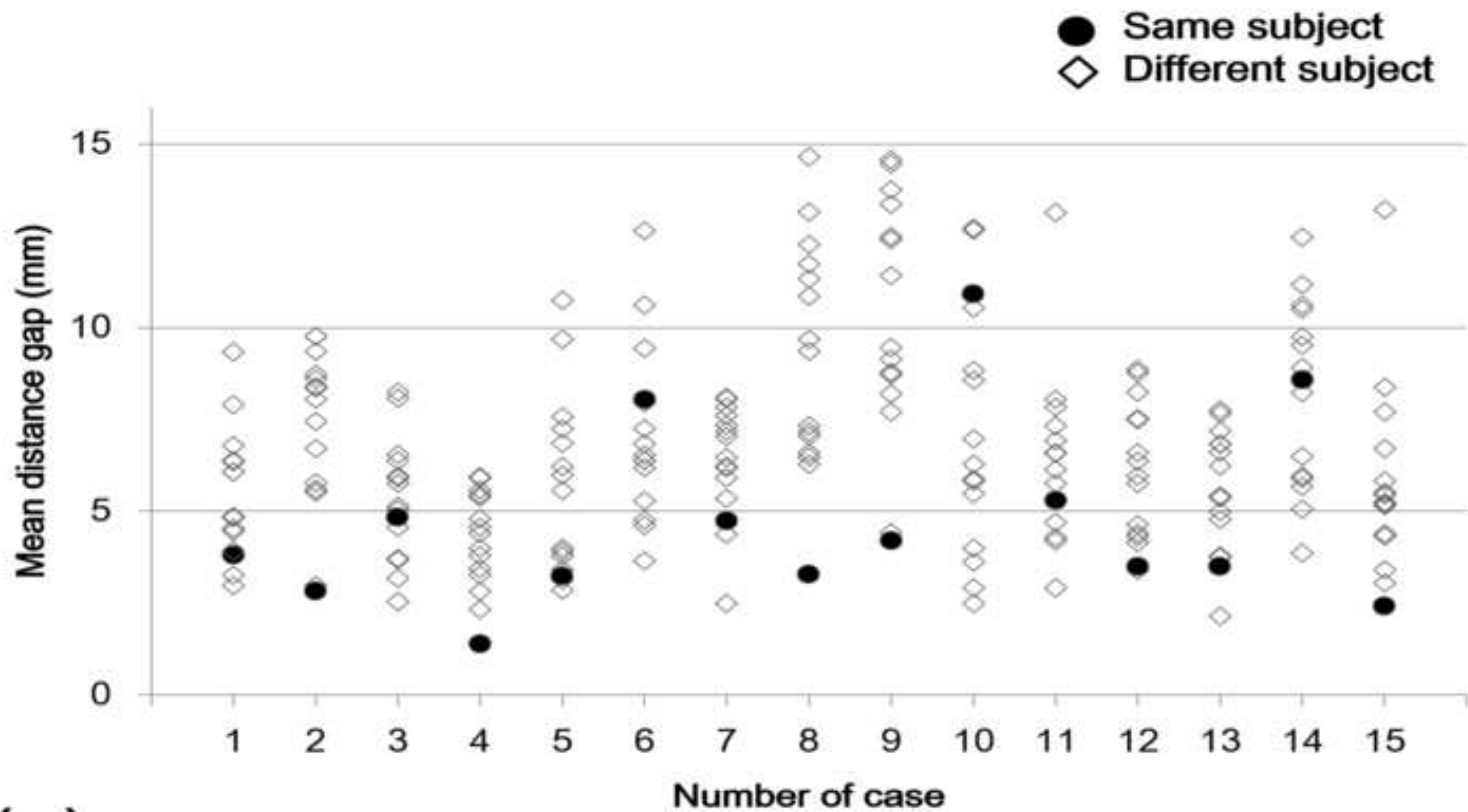

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Fig.3d

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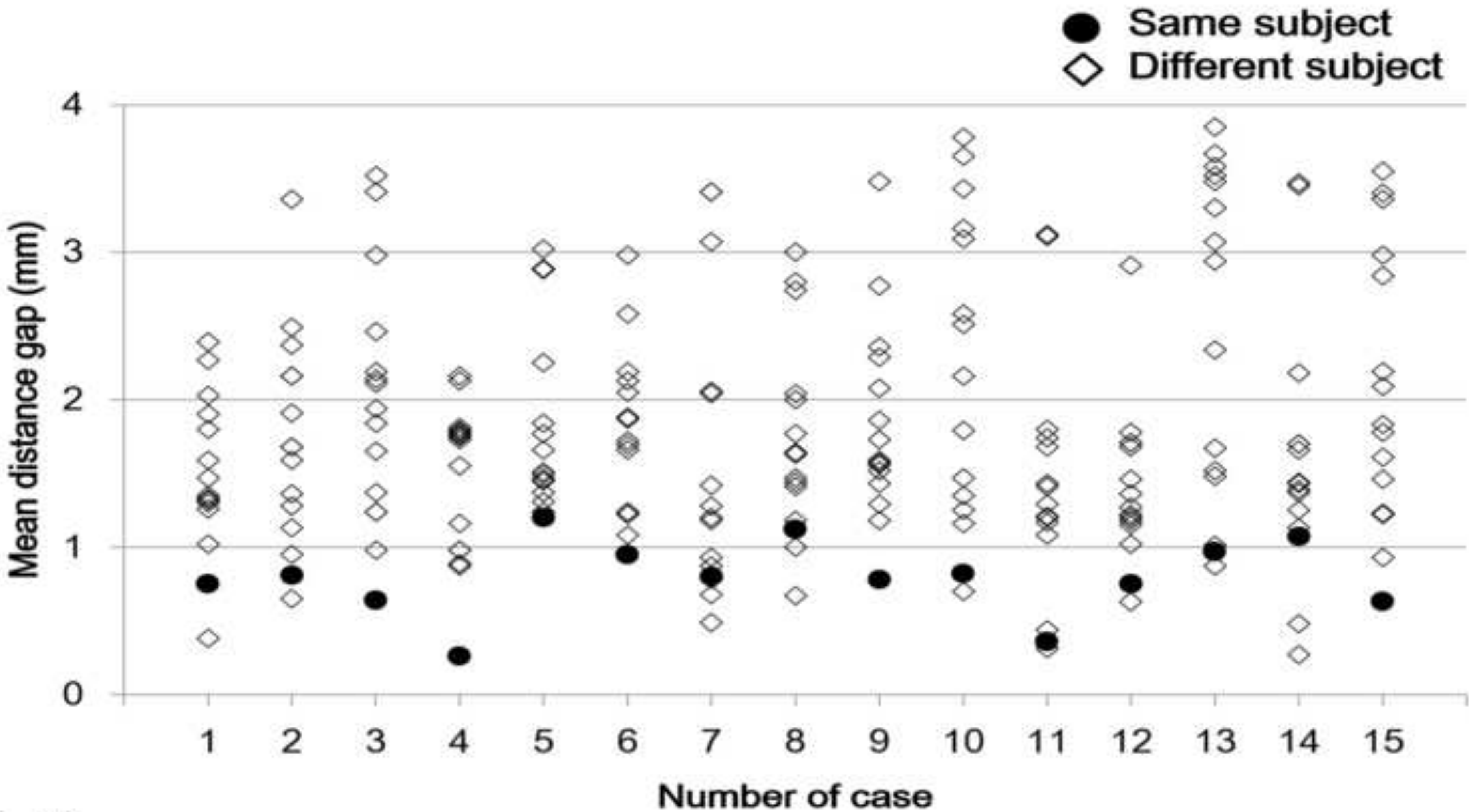

(d)

Fig.4

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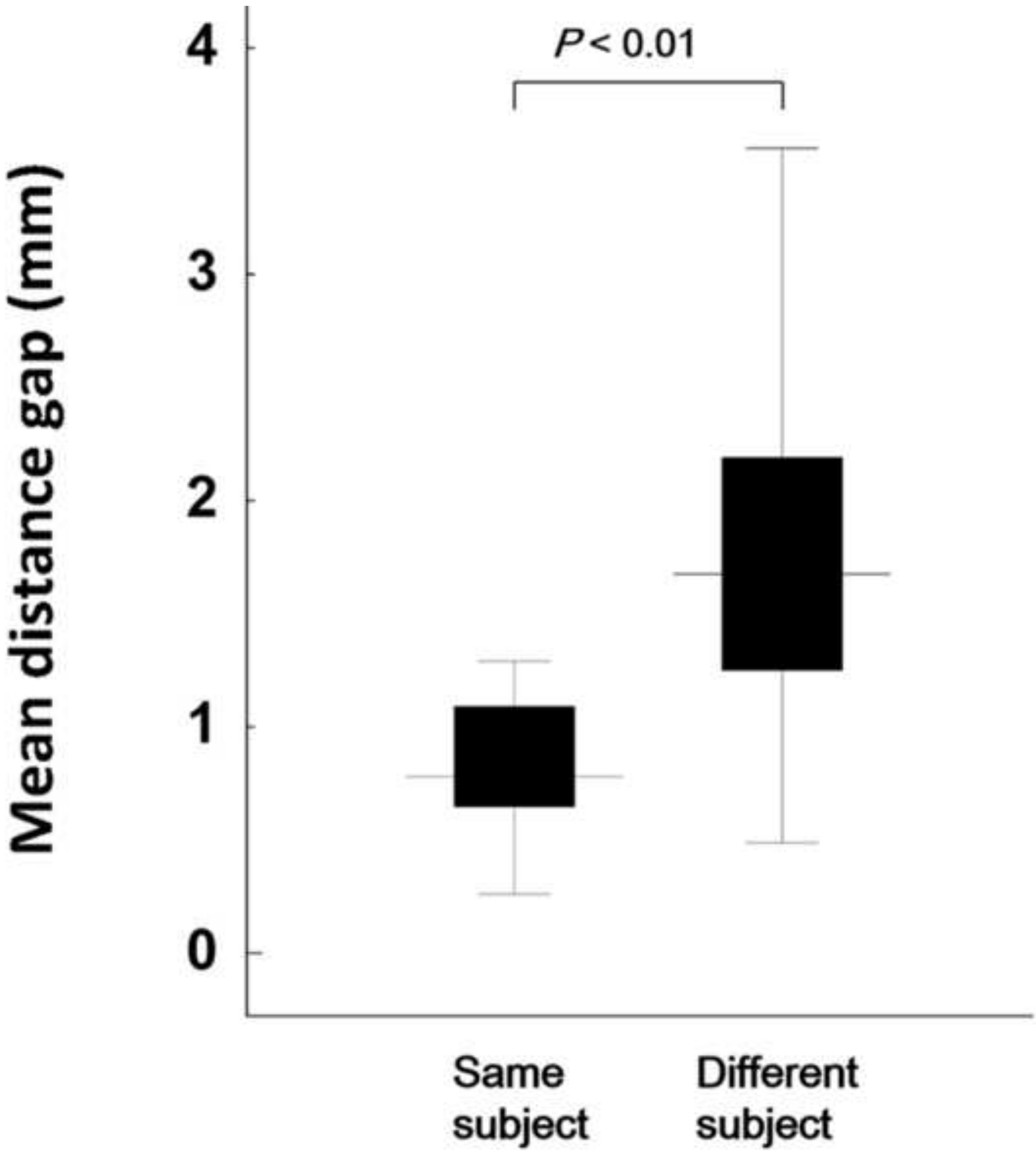

Fig.5a

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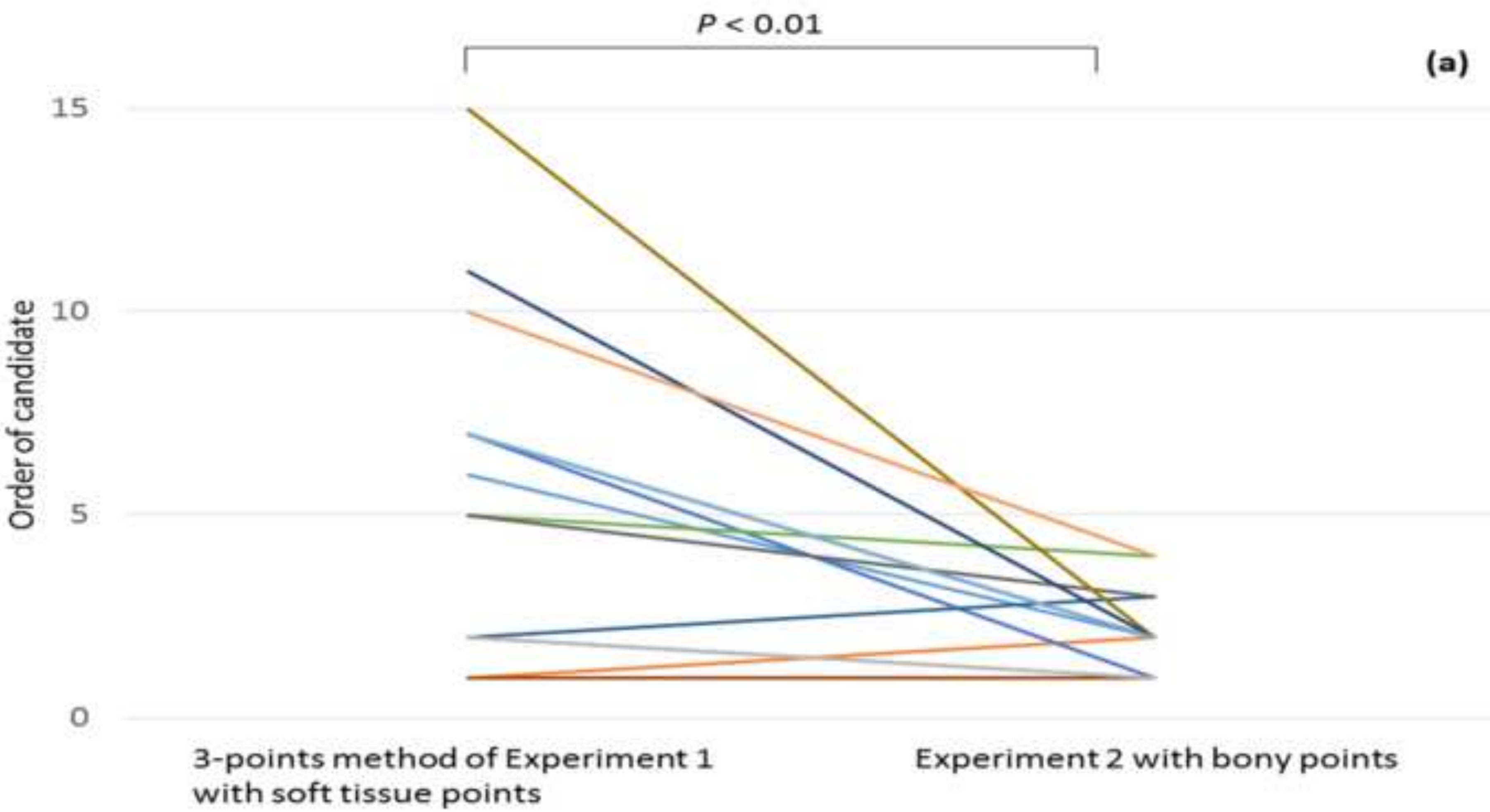

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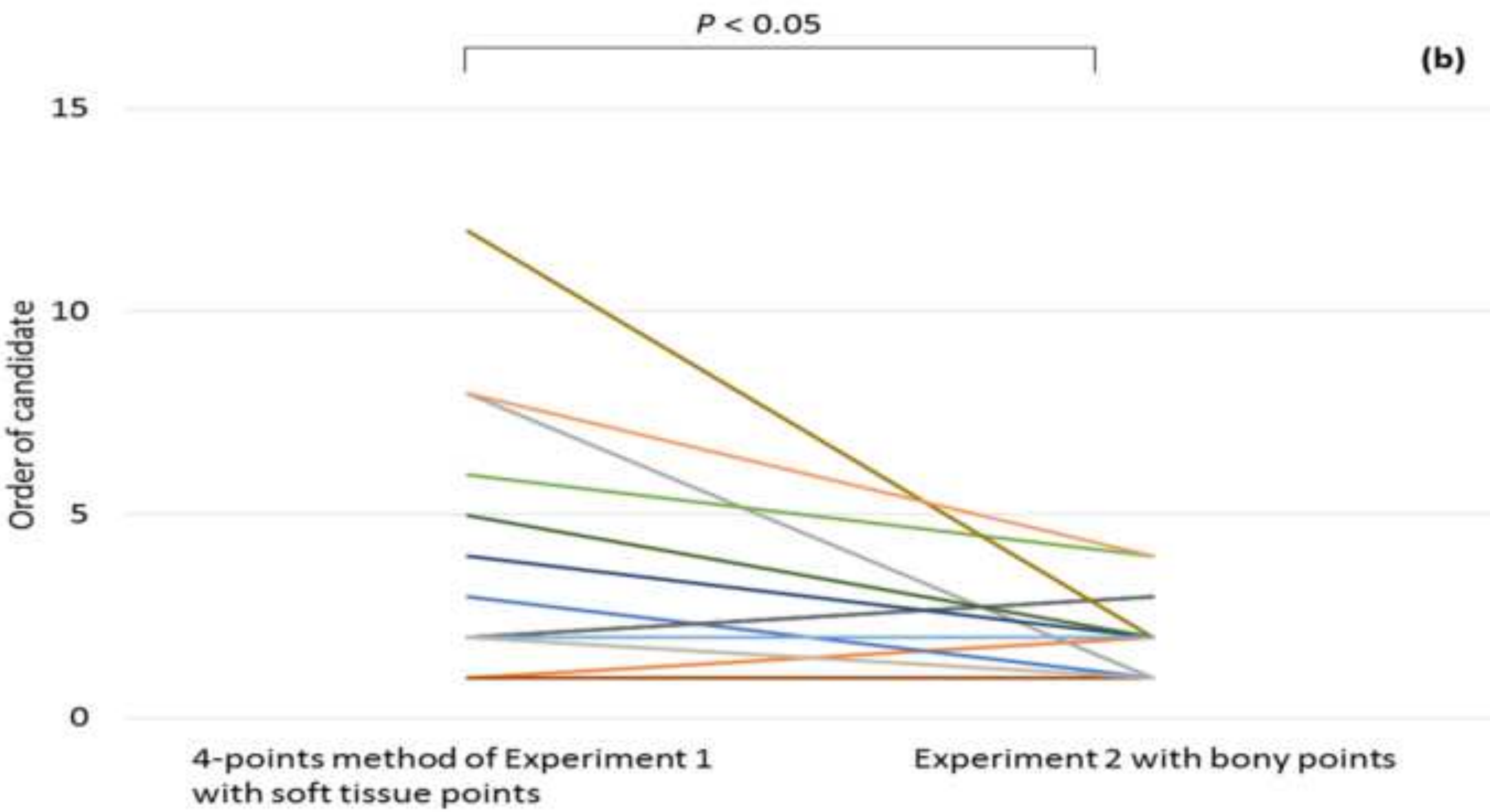
P < 0.05
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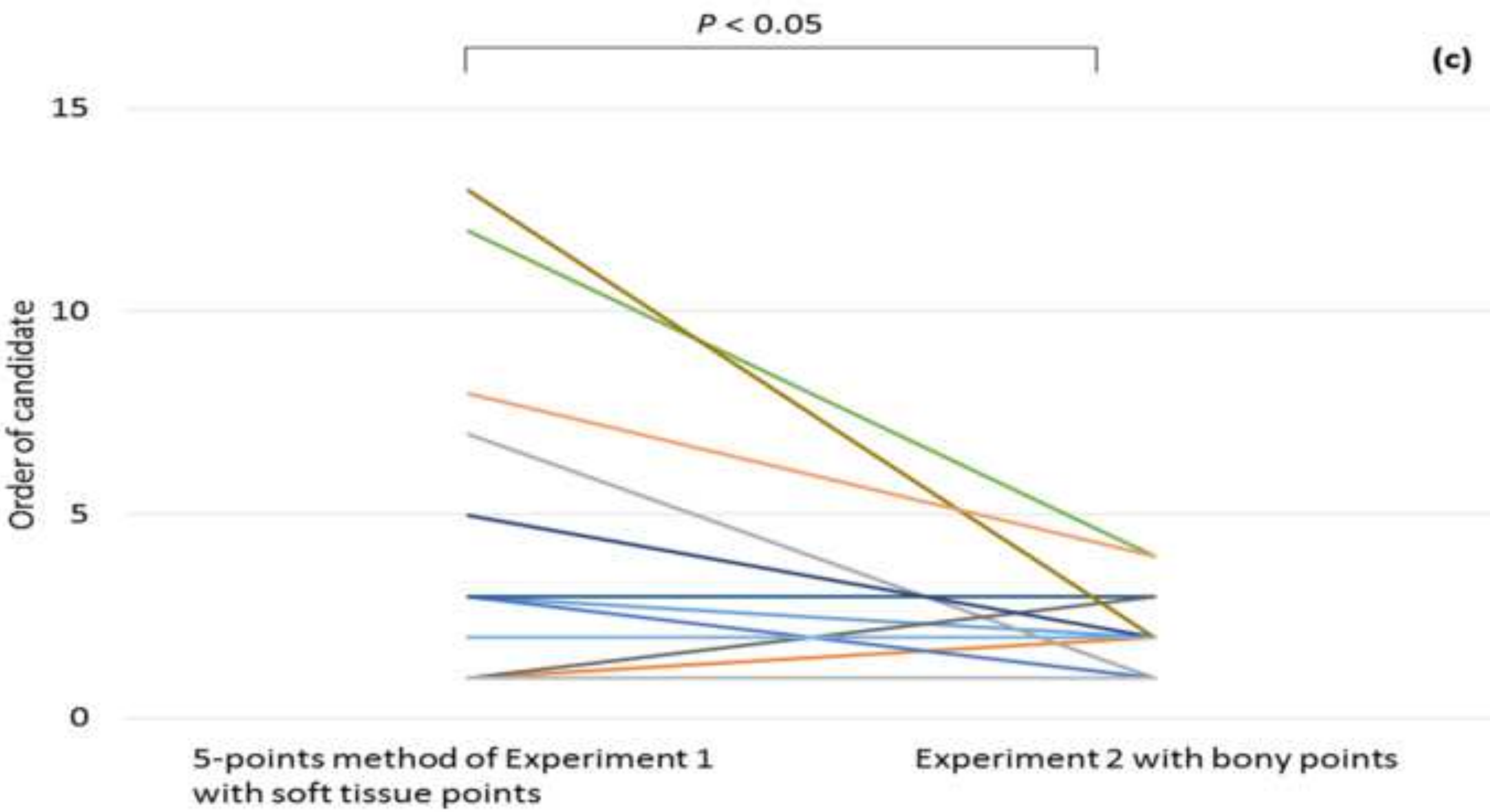
Order of candidate
4-points method of Experiment 1
with soft tissue points
Experiment 2 with bony points

Fig.5c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Order of candidate
5-points method of Experiment 1
with soft tissue points
Experiment 2 with bony points