The accuracy and safety of CT-guided iodine-125 seeds implantation assisted by 3D non-coplanar template for retroperitoneal recurrent carcinoma.

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Abstract

Purpose

To investigate the accuracy, dosimetric parameters and safety of 3D-printing non co-planar template (3D-PNCT) assisted CT-guidance for radioactive iodine-125 (125I) seed implantation brachytherapy (RSI-BT) for retroperitoneal recurrent carcinomas.

Methods and materials:

We enrolled 15 patients with 17 retroperitoneal recurrent carcinomas after external beam radiotherapy (EBRT). All patients received CT-guided 125I RSI-BT assisted by 3D-PNCT successfully. We compared the original needles insertion position, angular and the needle tips distance deviations of preoperative plan with that of intra-operative in brachytherapy treatment-planning system (B-TPS). The dosimetric parameters of RSI-BT were evaluated on preoperative plan, intra-operative real-time plan and postoperative plan, including D90, D100, V100, V150 and V200. The quality assurance of RSI-BT evaluated on conformal index (CI), external index (EI), homogeneity index (HI) of the targets were compared among preoperative plan, intra-operative real-time plan and postoperative plan. The peri-operation complications and re-radiation related toxicity were assessed.

Results

The median follow-up was 8.2 months (range 1-18.5 months). One patient lost follow-up after RSI-BT. 14 patients were assessed for response rate and toxicity. The mean entrance point distance deviation for all 165 needles was 4.50 ± 4.10 mm (range, 0–30). The mean angular deviation was 2.70 ± 3.00 degrees (range, 0–20). The needles tip distances deviation was 6.90 ± 6.00 mm (range, -30-28). D90 for preoperative plan, intra-operative plan and postoperative plan were 140.55 ± 23.93, 124.25 ± 28.04, 128.98 ± 22.75. There was significant difference between D90 of preoperative plan with that of intraoperative plan (p = 0.036). Four patients reached CR, three patients reached PR, three patients were SD and three patients was PD. Four patients with middle pain became moderate, two with moderate pain relived completely after RSI-BT. The others parameters showed no differences among preoperative plan, intraoperative plan and postoperative plan. The perioperative complications were observed in four patients, including three patients of grade 1 and one patient of grade 2. No ≥ grade 3 side-effects were observed.

Conclusion

CT-guided 125I RSI-BT assisted by 3D-PNCT was a safe, accurate and feasible strategy for recurrent carcinomas located in retroperitoneal regions.

Introduction

The anatomic construction in retroperitoneal region was deep and complex due to a majority of important organs located there, such as blood vessels, spinal cord. The most common carcinomas in retroperitoneal regions was metastasis originated from cervical cancer, pancreatic cancer, gastric cancer and adrenal metastasis, while the primary carcinoma was mainly soft tissues sarcoma [1–5]. The standard treatment approach was EBRT plus chemotherapy for recurrent carcinoma after surgery or metastasis in the retroperitoneal region. However, the majority of recurrent patients after EBRT or EBRT combined with chemotherapy were often resistant to re-radiation or chemotherapy [6–10]. The salvage approach for recurrent patients was always deemed as a challenge, most of which was palliative treatment and mainly for relieve of the symptoms. The response rate (RR) of chemotherapy, which are the second line or salvage treatment regimens for cervical, pancreatic and gastric carcinoma, was unfavorable [11–13]. Most of patients suffered from severe pain and suboptimal quality of life (QOL).

125I RSI-BT belongs to low-dose rate brachytherapy (LDR-BT) which delivers locally high doses inside the targets
and rapidly drop off surrounding the normal tissues [14]. Transperineally ultrasound (US)-guided 125I RSI-BT was a standard modality for prostate cancer because of the excellent outcomes and minimally invasive procedure compared with surgery or EBRT [15, 16]. The disadvantages of US-guided RSI-BT included: (1) two-dimensional image reconstruction and low resolution; (2) unsuitable for carcinomas located in head and neck, thoracic, retroperitoneal, pelvic and spinal cord due to air or bony construction interferences; (3) the available commercial brachytherapy treatment planning system (B-TPS) was special for prostate carcinoma, with all needles arrangement kept in parallel and high dependence on ultrasound-guidance; (4) The available template was rigid and only for parallel needles trajectory, which was unsuitable for no co-planar insertion. The suboptimal doses conformity for specially location tumors was unavoidable. With the development of 3D-printing techniques, the individualized template was invented and named as 3D-printing non co-planar template (3D-PNCT) [17]. However, 3D-PNCT combined with CT-guidance for long distance puncture pathway achieved optimal dosimetry conformity in the targets. Thus, the accuracy and safety of 3D-PNCT assisted CT-guidance RSI-BT were investigated in this study.

**Methods And Materials**

**Patients indications selection**

Totally 15 patients with 17 lesions from recurrent carcinomas located in retroperitoneal regions who received EBRT were enrolled in this study (Table 1). The pre-RT doses ranged from 30 to 80 Gy. The median tumor volume was 23.1 cc (range, 5.1–68.6 cc). The indications for selected patients in this study were as follow: (1) pathological or radiological diagnosis were confirmed; (2) the diameter ≤ 5 cm and no invasion to intestinal tube or spine; (3) preoperative plan showed that the needle channel pathway and the prescribed doses were satisfactory; (4) predicted survival time ≥ 3 months. The exclusion criteria were as follow: (1) severe coagulation functional disorder; (2) tumor invasion into spine or intestine; (3) preoperative plan showed that there was no satisfied needle puncture pathway. The study was approved by the ethic committee of our hospital.

| Table 1 General information |
|-----------------------------|
| **Number** | **Percentage (%)** |
| **Gender** | |
| male | 7 | 46.7 |
| Female | 8 | 53.3 |
| **Age, years** | 58 (38–78) |
| **Primary tumor location** | |
| Esophagus | 3 | 20 |
| Pancreas | 1 | 6.7 |
| Cervix | 4 | 26.7 |
| Location               | Cases | Percentage |
|------------------------|-------|------------|
| Corpus uteri           | 3     | 20         |
| Liver                  | 1     | 6.7        |
| Colon                  | 1     | 6.7        |
| Ureter                 | 1     | 6.7        |
| Cardia                 | 1     | 6.7        |
| Stage                  |       |            |
| I                      | 3     | 20         |
| II                     | 4     | 26.7       |
| III                    | 4     | 26.7       |
| IV                     | 4     | 26.7       |
| Pathological type      |       |            |
| Squamous cell carcinoma| 7     | 46.7       |
| Adenocarcinoma         | 2     | 13.3       |
| Hepatocellular carcinoma| 1   | 6.7        |
| Urothelium carcinoma   | 1     | 6.7        |
| Endometrioid adenocarcinoma| 3 | 20        |
| Neuroendocrine carcinoma| 1   | 6.7        |
| Previous treatment     |       |            |
| EBRT                   | 15    |            |
| Prescribed doses (Median, range) | 50.4(30–80) | |

| Implantation Location  |         |
|------------------------|---------|
| Retroperitoneal lymph node | 13   | 76.5     |
| Adrenal gland          | 3       | 17.6     |
### Table 2
The deviation of position, angle and distance of needles between preoperative plan and intraoperation plan in B-TPS.

| No. of needles | Deviation of position (mm) | Deviation of angle (°) | Deviation of distance (mm) |
|----------------|-----------------------------|------------------------|---------------------------|
|                | Mean | Range | SD  | Mean | Range | SD  | Mean | Range | SD  |
| 165            | 4.5  | 0–30  | 4.1 | 2.7  | 0–20  | 3.0 | 6.9  | -30 ~ 28.1 | 6.0 |
| P              | 0.000 |        |     | 0.000 |        |     | 0.000 |        |     |

### Table 3
The dosimetric parameters of 125I seeds implantation (x ± s)

|                         | Preoperative | Intraoperative | Postoperative | P*        | P**       | P***     |
|-------------------------|--------------|----------------|---------------|-----------|-----------|----------|
| Number of needles       | 10.76 ± 4.05 | 9.76 ± 3.80    | 9.82 ± 3.75   | 0.010     | 0.007     | 0.332    |
| Number of seeds         | 48.00 ± 16.80| 46.82 ± 18.25  | 47.88 ± 18.75 | 0.595     | 0.962     | 0.070    |
| GTV volume(cm3)         | 26.41 ± 16.2 | 26.71 ± 17.43  | 26.72 ± 17.46 | 0.585     | 0.629     | 0.952    |
| D90                     | 140.55 ± 23.93| 124.25 ± 28.04 | 128.98 ± 22.75| 0.036     | 0.102     | 0.338    |
| D100                    | 66.70 ± 16.77| 58.14 ± 21.24  | 61.51 ± 15.86 | 0.169     | 0.459     | 0.500    |
| V100                    | 24.83 ± 15.94| 22.71 ± 12.1   | 23.64 ± 13.75 | 0.142     | 0.317     | 0.129    |
| V150                    | 20.02 ± 13.32| 17.45 ± 10.15  | 18.74 ± 11.53 | 0.058     | 0.302     | 0.056    |
| V200                    | 14.51 ± 11.02| 12.38 ± 8.07   | 23.59 ± 8.97  | 0.119     | 0.451     | 0.072    |
| CI                      | 0.54 ± 0.16  | 0.50 ± 0.15    | 0.50 ± 0.17   | 0.068     | 0.342     | 0.985    |
| EI                      | 0.90 ± 1.00  | 0.91 ± 0.90    | 1.06 ± 0.99   | 0.981     | 0.553     | 0.119    |
| HI                      | 0.22 ± 0.07  | 0.25 ± 0.09    | 0.21 ± 0.08   | 0.380     | 0.637     | 0.117    |

Note: P* refers to preoperative vs. intraoperative; P** refers to preoperative vs. postoperative. P*** refers to intraoperative vs. postoperative.
Table 4

Perioperative and postoperative complication of seeds implantation.

|                          | RTOG/CTC Scoring Schema |
|--------------------------|-------------------------|
|                          | G1 | G2 | G3 | G4 |
| Perioperative             |    |    |    |    |
| Pneumothorax             | 0  | 1  | 0  | 0  |
| Hematemesis              | 1  | 0  | 0  | 0  |
| Hemorrhage of digestive tract | 1  | 0  | 0  | 0  |
| Fever                    | 0  | 0  | 0  | 0  |
| Infection                | 0  | 0  | 0  | 0  |
| Postoperative            |    |    |    |    |
| Skin                     | 1  | 0  | 0  | 0  |

Patients Preparation And Preoperative Plan

Patients were set-up on the CT simulator and immobilized at prone position with vacuum bad. Both native and contrast CT scan were performed with 5 mm thickness before RSI-BT. The CT scan slices were transferred into B-TPS (Beijing University of Aeronautics and Astronautics and Beijing Astro Technology Co., Ltd) for preoperative plan. Planning system source data originated from the latest official manuscripts of the American Association of Physicists in Medicine (AAPM) [18, 19].

The Principle Of Preoperative Plan Design

The needles should be kept in parallel, with distance of 1-1.5 cm. If the organs at risk (OARs) interference for the needles, no co-planar needles distribution was adapted to satisfy the targets doses conformity and the lowest doses to normal tissue. Then we delineated targets and OARs, and defined prescribed doses and limitation of OARs. Clinical target volume (CTV) was expanded from gross tumor volume (GTV) by 5–6 mm in three dimensions. Prescribed doses were 110–160 Gy, the radioactivity of 125I seed was 0.4–0.7 mCi (The seed model was 6711 – 1985, Shanghai GMS Pharmaceutical Co., Ltd). The principles of seeds distribution were sparse in the center and dense at the peripheral zone of the targets (Fig. 1).

3D-PNCT Design And Production

The B-TPS data were imported into 3D imaging and reverse engineering software for individualized digital modeling design. 3D-PNCT were obtained by a 3D curing rapid prototyping machine and the material processing of medical curing resins. The 3D-PNCT contained certain information such as body-surface characteristics, X, Y axle coordinate, 2–3 stable needles and dummy needles channel holes.

We classified recurrent retroperitoneal carcinoma into 3 subgroups according to the recurrent locations referenced to spinal cord. The definition of subgroup included: (1) Type 1: the recurrent tumors located in left side of spinal cord and the front margin did not spread to the middle line, the needles inserted from left side; (2) Type 2: the recurrent tumor located before the front edges of spinal cord, the needles inserted from two sides; (3) Type 3: the recurrent tumors located in right side of spinal cord and the front margin did not spread to middle line of spinal cord, the needles inserted from right side (Fig. 2).
The Work-flow Of 125I RSI-BT

The procedures of 125I RSI-BT were as follow: (1) patients were set-up again with template fixed on the patient body by 2–3 stable needles; (2) CT-scan was performed to verify the stable needles position. If the deflection errors were ≤2 mm, we adjusted the needles position until the deviation ≤ 2 mm. (3) The other implant needles were inserted into the targets; (4) CT scan was performed again to check the tips of the needles position. If the deflection errors were ≤2 mm, we made a fine adjustment until the errors were ≤ 2 mm; (4) 125I seeds were implanted with applicators according to the preoperative plan and the needles withdraw to the skin below 1 cm; (5) CT scans were conducted again to verify the seeds distribution. If the seeds distribution did not meet the requirements of preoperative plan, seeds savage implantation was performed immediately and all the needles were taken out; (6) CT scan was performed again and transferred the slices into the B-TPS for postoperative doses parameters calculation [17]. After RSI-BT, the patients return to patients wards and received perioperative prophylactic antibiotics and hemostasis one day and discharged 24 hours later.

Postoperative Plan For Dosimetric Verification

The D90, D100, V100, V150 and V200 were recognized as the dosimetric parameters of tumor target. The quality assurance comparison of RSI-BT involved CI, EI and HI among preoperative plan, real-time plan and postoperative plan.

Definition Of End Points:

Main-end points: (1) To evaluate the accuracy of needle distributions, we compared the preoperative planned with intra-operative on B-TPS. The CT images in preoperative plan were confused with intra-operative real-time CT scan images depending on bone construction as the references. The needles tips positions, the needles angles and the tips depth were measured; (2) The D90 (doses delivered to 90% of the target volume), D100, V100 (the percentage of the target volume receiving at least 100% of the prescribed doses), V150 and V200 were calculated; (3) The quality of RSI-BT in preoperative plan, real-time and postoperative plan targets were compared with CI, HI and EI.

Secondary main-point: (1) Peri-operation side effects assessment included bleeding, fever, infection, fistula; (2) The radiation related complications were assessed according to RTOG Common Toxicity Criteria; and (3) Pain relief rate was evaluated.

Follow-up

After RSI-BT, routine follow-up was performed every 3 months in the first 2 years and every 6 months from 3 to 5 year, followed by annual evaluation. CT scans of the thorax and abdomen was part of the follow-up for contrast. Patients underwent clinical evaluation and laboratory testing. The evaluation of efficacy was based on the Response Evaluation Criteria in Solid Tumors (RECIST) v1.1, including complete response (CR), partial response (PR), progressive disease (PD), and stable disease (SD). Adverse reactions were evaluated by the Common Terminology Criteria for Adverse Events (CTCAE) v 4.0 (CTCAE 2010) [20, 21]. Pain was assessed using a numerical rating scale (NRS) which was categorized into five grades: 0 for no pain, 1–3 for mild pain, 4–6 for moderate pain, 7-9 for severe pain, and 10 for unbearable pain. The pain score in one month after the treatment was compared with that of pre-operation.

Statistical analysis

The characteristics of patients were expressed as continuous variables and/or categorical variables. Continuous variables were compared using the t-test or rank-sum test, whereas the categorical variables were compared using the chi-square or Fisher’s exact test. ORR was expressed based on the number and percentage of patients. SPSS 21.0 software (SPSS, Chicago, IL) was used for statistical analysis. The P value < 0.05 was considered as statistical significance.
Results

The median follow-up time was 8.2 months (range, 1-18.5 months). One patient lost follow-up. The 15 patients with 17 lesions were enrolled for accurate assessment and 14 patients were involved for side-effect analysis. The median GTV in the preoperative plan, intra-operative plan and postoperative plan were 26.41 ± 16.2, 26.71 ± 17.43, 26.72 ± 17.46, respectively (p>0.5). The mean needles tips deviation for all 165 needles was 4.50 ± 4.10 mm (range, 0–30, p = 0.000). The mean angular deviation was 2.70 ± 3.00 degrees (range, 0–20, p = 0.000). The needles depth deviation was 6.90 ± 6.00 mm (range, -30-28, p = 0.000). D90, D100, V100, V150 and V200 for preoperative plan, intra-operative plan and postoperative plan were 140.55 ± 23.93, 124.25 ± 28.04, 128.98 ± 22.75; 66.70 ± 16.77, 61.51 ± 15.86; 24.83 ± 15.94, 22.71 ± 12.10, 23.64 ± 13.75; 20.02 ± 13.32, 17.45 ± 10.15, 18.74 ± 11.53; 14.51 ± 11.02, 12.38 ± 8.07, 23.59 ± 8.97. The CI, EI and HI were 0.54 ± 0.16, 0.50 ± 0.15, 0.50 ± 0.17; 0.90 ± 0.90, 0.91 ± 0.90, 1.06 ± 0.99; 0.22 ± 0.07, 0.25 ± 0.09, 0.21 ± 0.08. There were no statistically significant differences in D100, V100, V150, V200, CI, EI and HI in GTV between pre-pan and intra-operative plan, preoperative plan and intra-operative plan and intra-operative plan with that of postoperative plan (P > 0.05); while there was only significant differences between D90 (P < 0.05) of preoperative plan with that of intra-operative plan. There was no differences between intra-operative doses optimization with that of postoperative plan.

When it comes to response rate, CR was observed in four patients. PR was shown in six patients. SD was observed in three patients. PD was observed in three patients. Among them, six patients gained pain relief. The peri-operation complications were observed in four patients, including three of grade 1 and one of grade 2. No ≥ grade 3 side-effects were observed.

Discussion

High-dose-rate BT (HDR-BT) is a very important modality in RT, and commonly used in breast cancer, cervical cancer, prostate and skin cancer treatment [22–23]. The outcome of HDR-BT combined with surgery for selected recurrent soft tissue carcinomas were favorable, however, with the complication rates ranged from 15–50% [24]. The 125I RSI-BT belongs to LDR-BT and has advantages as follow: (1) single performance; (2) real-time image-guidance; (3) the local boost dose to target; (4) minimal invasion and fast recover. In order to expand the indications of RSI-BT, CT-guidance technique was integrated into RSI-BT in 2002 in China, which was used to treat head and neck, thoracic, abdomen, and spinal vertebrate carcinoma [25–30]. The CT-guided 125I RSI-BT was very safety and effective approach for anti-cancer treatment, especially for recurrent or metastasis carcinomas. The majority of recurrent carcinomas located in retroperitoneal regions had lost the opportunity to further resection or re-radiation after EBRT due to the surrounding OARs doses limitation such as intestine, spinal cord and blood vessels. Yao et al reported that 17 patients with 19 retroperitoneal lymph node recurrences after EBRT underwent CT-guided 125I RSI-BT. The actuarial D90 of postoperative plan was 100-198 Gy (median, 126.5 Gy). Nine patients with pain decreased to mild pain one-three weeks after RSI-BT. Pain-free survival time ranged 2–15 months (median, 5 months). The OS rate was 100%. The median LC was 15 months. The 1- and 2-year LC was 63.2% and 42.1%, respectively. 12 patients (70.6%) died of distant metastasis. Two patients (11.8%) survived with distant metastases and without evidence of local recurrence. Median OS was 10 months. The 1- and 2-year OS were 38.1% and 15.3%, respectively. No major complications related to RSI-BT occurred during or after treatment [31]. There were some drawbacks as follow: (1) It is a long period to train a skilled puncture personnel; (2) The quality control of RSI-BT was not often concomitant with preoperative plan design due to OAR interferences such as blood vessels, nerve and bone construction. The analysis of CBased dosimetry revealed that doses coverage of RSIBT postoperative plan was often lower than that in preoperative plans; (3) The operation time was average 2–3 hours because that CT scan was conducted to check every needle position for several times. Thus, investigators explored the possibility of template-assisted CT-guidance to overcome these limitations, which theorized that the precision placement of seeds to the periphery of the targets in a highly conformal manner, ensured good tumor control and minimized the doses to
the surrounding OAR.

With the development of 3D-printing techniques, the 3D-printing substance has explored across the medical field. Andrews et al used stereolithography printers to print the temporal bone anatomy of patients with congenital aural atresia to plan atresia plasticity [32]. D’Urso published their early study with 3D-printed models of craniofacial and maxillofacial defects in 45 patients [33]. Their experience showed improved measurement accuracy and suggested modest improvement in operative time while improving patient education [34]. BT plays an important role in cancer treatment as monotherapy or combined with EBRT. The key techniques were the image-guidance combined with template assistance which assured the applicators or needles placed into the targets accurately as preoperative plan designed, especially for the breast, prostate and skin cancer [14–15]. Those cancer anatomic locations were relatively simple and the applicators or needles can easily be inserted into the interested targets and kept in parallel arrangements. The optimal doses patterns of the targets were achieved to maximize the doses to the cancer and minimize the doses to normal tissues. However, the carcinomas located in head and neck, thoracic, retroperitoneal, pelvic and spinal cord sites were very different from the above location. The rigid template for prostate or cervical cancer cannot satisfy the requirements for complex anatomy construction and shape of tumors with RSI-BT.

Huang et al first reported the accuracy of RSI-BT in 31 patients with recurrent and local advanced head and neck malignant tumors. The preliminary study confirmed that this approach was easier and more accurate. The D90, V100 and V150 were all meet the treatment requirements [35]. The carcinomas occurred in head and neck regions were relatively stable and superficial, so it is relatively easy for template to fix with the patient anatomic construction and the needles puncture deviation was infrequent. We applied the individualized template for the carcinomas in a deep location and long-distance puncture pathway. The body 3D-printing individual, digital and co-ordinate template was invented in 2015. The 3D-PT was classified into 3D-printing co-planar template (3D-PCT) and 3D-PNCT. The indications of 3D-PCT were only for needles insertion kept in parallel way and the needles holes interval was 0.5–10 mm which assured that the targets doses pattern meets the preoperative plan requirements. When the needles pathway was impeded by OARs with 3D-PCT assistance, the needles were adjusted to the near holes to keep away from OARs, or established an artificial channel with puncher for bone construction. The indications of 3D-PNCT can apply to almost all the carcinomas in different locations for RSI-BT, the targets doses conformity of which was optimal [36]. The advantages of 3D-PNCT included: (1) The X, Y axle coordinate located in the center of the template which can match with the marked lines on the patient body surface; (2) Extra 2–3 stable needles holes designed on the template was used to immobilize the template on patient body. The stable needles position should be designed near the bony construction as references and easy to compare with preoperative plan images; (3) The dummy needles channels were designed to overcome the organ motion during operation. Salvage seeds implantation can be performed immediately due to suboptimal doses pattern on the real-time plan optimization, in order to avoid the patients returned to hospital for second time seeds implantation. The increasing accuracy and universality of RSI-BT promoted it to be an alternative minimally invasive and precise ablation approach which was deemed as stereotactic ablation brachytherapy (SABT).

The effective treatment modality for recurrent carcinomas in retroperitoneal locations still face a giant challenge, especially for recurrence after EBRT. Our preliminary study showed the possibility and safety of 3D-PNCT assisted CT-guided RSI-BT, which suggested that intra-operative D90 was significantly different with that in preoperative plan, and there was no significant difference between preoperative plan and postoperative plan through real-time doses optimization. The needles position deviation for recurrent carcinomas located in retroperitoneal region might occur, due to the long distances puncture, the organ motion and OAR interferences. The difference of needles tips position, angles and depth among preoperative plan, intra-operative plan and postoperative plan were all significant, but no significant differences were seen on the CI, EI and HI among preoperative plan, real-time plan, postoperative plan, which suggested that the intra-operative needles position adjustment and doses optimization were very important. The postoperative plan D90 of RSI-BT would reach the preoperative plan designed requirements even for carcinomas located in depth position. The peri-operation complications were moderate. The radiation-related toxicity rates were acceptable.
Conclusion

3D-PNCT assisted CT-guided RSI-BT is a safe and effective approach in treatment of recurrent carcinomas in retroperitoneal regions. It is worth warranted to conducted more multiple, prospective and randomized clinical trials to compare the long-term efficacy of 125I RSI-BT with second line treatment.

Declarations

Ethics approval and consent to participate

All patients provided written informed consent to participate in this study.

Consent for publication

Not applicable

Availability of data and materials

No additional data are available.

Competing interests

All authors declared that there are no conflicts of interest.

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Authors' contributions

Dr. Weijuan Jiang collected the data, drafted the manuscript and did the statistical analysis. Dr. Ping Jiang, Dr Yuliang Jiang and Dr Zhe Ji were in charge of verifying patients’ treatment plans and directing manuscript writing. Dr. Shuhua Wei collected the material, reviewed and corrected this manuscript. Haitao Sun, Jinghong Fan, Weiyan Li and Yuxia Shao were responsible for collection of clinical data. Dr. Junjie Wang was responsible for the supplementation/refinement of clinical data, and carried out statistical analyses.

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Figures
Figure 1

The work-flow of 3D-PNCT assisted CT-guidance RSI-BT. (a) 3D-PNCT. (b) 3D-PNCT reconstruction on CT images. (c) 3D model view of bony anatomy and the puncture needles distribution reconstruction. (d) 3D-PNCT set-up: (e) stable needles insertion based on preplan, (f) seed needles insertion (g) pre-plan, (h) intraoperative real-time plan and (i) postoperative plan.
Figure 2
The pattern of recurrent retroperitoneal carcinoma