CT Perfusion in Predicting Treatment Response of Nasopharyngeal Carcinoma

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Background: *Direct nasopharyngoscope with biopsy is the gold standard for assessing tumor response of nasopharyngeal carcinoma (NPC). It is invasive with risk of hemorrhage or infection.*
Objective: *Explore the usefulness of pre-treatment CT perfusion (CTP) and clarify the parameters in predicting the treatment response.*
Material and Method: *Twelve patients with histologically proven NPC who underwent pretreatment contrast enhanced CT (CECT) and CTP with parameters (blood flow (BF), blood volume (BV) and permeability), followed by CECT at three months after complete concurrent chemo-radiotherapy or radiotherapy were included in this prospective, cross-sectional study. Pre- and post-treatment primary tumor volumes based on free hand drawn region encompassing the entire primary tumor were measured and compared. The response to therapy was also assessed by RECIST guideline version 1.1, based on sum of the diameters of longest diameter for primary tumor and minimal transverse diameter for nodal lesions for all target lesions on the pre- and post-treatment imaging, and classified into "Non-response" group and "Complete response" group. Statistical analysis was performed using Pearson's correlation coefficients and Mann-Whitney U test.*
Results: *Ten and two patients (83.3%, 16.7%) belonged to "Complete response" and "Non-response" groups respectively. Elevated permeability, BF and BV had a following trend of positive correlation with degree of primary tumor volume reduction without statistical significance. The values of permeability, BF, and BV had a trend to be higher in "Complete response" group compared with "Non-response" group (p = 0.053, 0.390 and 0.519 respectively). The permeability had the highest predictive value with an area under the ROC curve of 0.95 and cutoff value of 45 ml/100 g/min (sensitivity, 100%; specificity, 90%).*
Conclusion: *Pre-treatment CTP can be useful non-invasive tool in predicting treatment response of NPC. Permeability is the excellent parameter used to differentiate between complete and non-response groups.*

Keywords: *CT perfusion, Prognosis, Outcome, Response, Permeability, Blood flow, Blood volume, Nasopharyngeal carcinoma*

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Squamous cell carcinoma is the most common cancer originating in the nasopharynx. Nasopharyngeal carcinoma (NPC) differs significantly from other cancers of head and neck in its occurrence, causes, clinical behavior, and treatment. NPC is uncommon in the United States and most western nations, representing less than 1 per 100,000 population but common in certain regions of China, South East Asia, and Africa. In Thailand, it is the most common head and neck cancer with an incidence rate of 3.1 per 100,000 population[1].

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NPC is associated with infection of Epstein-Barr virus (EBV), genetic susceptibility, consumption of salted fish containing carcinogenic nitrosamines[2]. Diagnosis of NPC is based on clinical and radiological examination and verified histologically by biopsy. Radiotherapy is the primary treatment modality. Although excellent control can be achieved for patients with early disease, significant survival benefit could be achieved by concurrent chemotherapy for locoregionally advanced disease[3].

Imaging, whether by computed tomography (CT) or magnetic resonance imaging (MRI), is generally performed for the purpose of evaluation of tumor extent and nodal metastasis[4]. MRI has the advantages of better tissue contrast, multiplanar capacity, and lack of radiation and bone beam-hardening artifacts.

It is well accepted that MRI demonstrated early primary tumor involvement more precisely and deep primary tumor infiltration more easily, compared with CT. MRI is superior to CT in demonstrating regional lymph node metastasis, because it can identify smaller nodes, discriminating individual lymph nodes from direct tumor extension and the adjacent normal structure and metastatic lymph nodes[5]. However CT is more economically feasible, rapid, and widely accessible. NPC staging is usually assessed by clinical examination, combined with contrast enhanced CT (CECT) in many lower income countries.

CT perfusion (CTP) is an imaging technique that can be readily incorporated into the routine CT protocols that continue to provide the mainstay for anatomical imaging in oncology to provide an in vivo marker of tumor angiogenesis. By capturing physiological information reflecting the tumor vasculature, CTP can be useful for diagnosis, risk-stratification, therapeutic monitoring, tumor progression, or recurrence[6]. CTP can assess physiologic parameters such as blood volume (BV), blood flow (BF), mean transit time (MTT) and capillary permeability surface area product (CP). Quantitative CTP measurements have been shown to be reproducible and have been validated against a number of reference methods for the brain and liver[7]. Direct nasopharyngoscope with biopsy is the gold standard for assessing tumor response. This procedure is invasive with risk of hemorrhage or infection. CECT combined with CTP prior to treatment may be the diagnostic imaging modalities to assess responsiveness in NPC treated by radiotherapy with or without chemotherapy.

The purpose of the present study was to explore the usefulness of pre-treatment CT perfusion (CTP) and to clarify the parameters in predicting the treatment response.

Material and Method

Patients

The present study was the prospective, cross-sectional study, performed at a university hospital during a consecutive 15-month period, between January 2010 and March 2011 with Institutional Review Board Approval. Written informed consent was obtained from all patients prior to enrollment. Eighteen patients with histologically proved NPC underwent pre-treatment imaging. The patients who had recurrent disease or under the age of eighteen were not included in the present study. Six patients who refused to perform post-treatment imaging were excluded from the present study. Twelve patients were enrolled, seven male (58.3%) and five female (41.7%). The mean age was a range of 30 to 72 years (mean 51.8, SD 11.7). All patients were newly diagnosed, consisted of non-keratinizing, undifferentiated subtype (n = 11) and differentiated subtype (n = 1). The tumors that were staged according to the Tumor, Nodes, and Metastasis (TNM) systems included one patient (8.3%) as stage I, two patients (16.6%) as stage II, three patients (25.0%) as stage III, four patients (33.3%) as stage IVA, and two patients (16.6%) as stage IVB. Local staging included T1 (n = 3), T2 (n = 4), T3 (n = 1), and T4 (n = 4). Two patients (16.7%) with early staging received treatment as radiation therapy. Ten patients (83.3%) received treatment as concurrent chemo-radiotherapy. Both conventional CECT and CTP of the nasopharynx were performed before undergoing to the therapy in each patient. Then, post-treatment CECT within three months after complete therapy was performed.

Imaging techniques

Conventional CT and CTP of the nasopharynx were performed by using a 64-slice multidetector scanner (Somatom Sensation Cardiac 64, Siemens Medical Solutions, Forchhein, Germany). An initial axial non-contrast CT (NCCT) of the nasopharynx was performed with 1.0-mm slice thickness followed by CTP. The area of the largest tumor diameter was defined from the NCCT localized image for measuring perfusion. Coverage of this area was set at 28.8 mm with a cycle time of one second and a scan time of 0.5 second. Seventy milliliters of non-ionic low-osmolar contrast material (300 mg/ml) was administered intravenously at an injection rate of 5 ml/sec. CTP was performed after a 5-second injection delay, using following parameters, 120 KVp, 100 mAs, and 2.4-mm contiguous sections with a scan time of 50 seconds. All 2.4-mm slice thickness images were reconstructed into 7.2-mm thick-sections before post-processing. After completion of the perfusion acquisition, 20 ml of the contrast material was administrated at 4 ml/sec, and then routine CECT of the nasopharynx and neck were performed with 5-second injection delay by using 2.4-mm contiguous section (120 KVp, 100 mAs).

The investigator (L.T.) with 10-year experience in head and neck imaging localized the tumor on axial CECT image on the basis of area of contrast enhancement at the slice where the tumor was largest. The perfusion data were postprocessed by using the

CT machine's accompanying workstation (Syngo multimodality workplace). The software utilized Patlak's two-compartment model. Perfusion analysis was assessed using three axial images acquired through the tumor with a slice thickness of 7.2 mm. Free-hand drawn region of interest (ROI) along the margin of enhancing tumor were manually placed onto the perfusion maps by using corresponding CECT image as reference for placing ROI (Fig. 1). None of the primary tumors appeared obviously necrotic on CECT image. Arterial input was determined by defining a circular ROI in the internal carotid artery at the level of the tumor. A time-density curve was then automatically generated followed by three perfusion color maps representing BF, BV, and permeability. These parameters were defined as follow:

- BF (ml/100 g/min), volume of blood moving through a given tissue per unit of time.
- BV (ml/100 g), total volume of blood in a given tissue region
- Permeability (ml/100 g/min), rate of leakage of contrast media from capillaries into the interstitium

The actual measurements of the CTP values were recorded. The investigator evaluating the imaging was blinded at the time of measurement from the results of the treatment response, because perfusion parameter values were assessed prior to performance of the post-treatment CECT.

Criteria of response

The investigators defined imaging analysis into two categories. First step, the measurements of pre- and post-treatment primary tumor volumes (in ml) were based on free hand drawn around the margin of enhancing area encompassing the entire primary tumor, performed on axial CECT images by using a fixed window level and width values (W350, L90) for all patients. The pre-treatment volumes were compared to those of the post-treatment imaging. Second step, the response to therapy was assessed by the Revised RECIST (Response Evaluation Criteria in Solid Tumors) guideline version 1.1[8] (Table 1). A sum of the diameters of longest diameter for primary tumor and minimal transverse diameter of the nodal lesions for all target lesions on the pre- and post-treatment imaging was calculated and compared as demonstrated in Fig. 2. We classified the patients into two groups, the patients that had stable disease and progressive disease belonged to "Non-response" group and the patients that had complete response belonged to "Complete response" group.

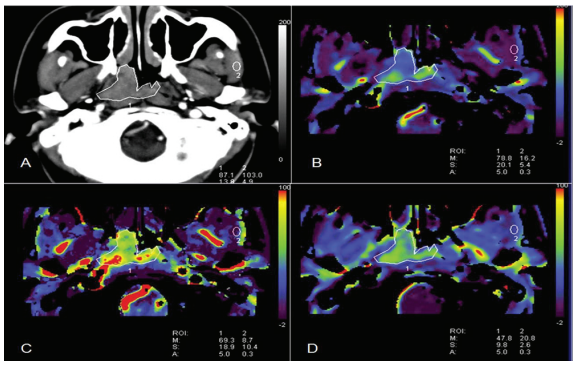

Fig. 1 Measurement of the CTP parameters obtained by hand drawn ROIs encompassing the visualized primary volume on the image of the tumor epicenter. A) CECT, B) BV map, C) BF map, D) permeability map.

Statistical analysis

Pearson's correlation coefficient was used to evaluate correlation between CTP parameters and degree of primary tumor volume reduction after treatment. To assess a statistically significant difference in value of CTP parameters between "Complete response" group and "Non-response" group, the Mann-Whitney U test was used. A receiver operating

Table 1. Response criteria (RECIST guideline version 1.1)

Response	Description
CR	Disappearance of all target lesions. Any pathological lymph nodes (whether target or non-target) must have reduction in short axis to <10 mm.
PR	At least a 30% decrease in the sum of diameters of target lesions, taking as reference the baseline sum diameters.
PD	At least a 20% increase in the sum of diameters of target lesions, taking as reference the smallest sum on study (this includes the baseline sum if that is the smallest on study). In addition to the relative increase of 20%, the sum must also demonstrate an absolute increase of at least 5 mm. The appearance of one or more new lesions is also considered progression.
SD	Neither sufficient shrinkage to qualify for PR nor sufficient increase to qualify for PD, taking as reference the smallest sum diameters while on study.

CR = complete response; PR = partial response; PD = progressive disease; SD = stable disease

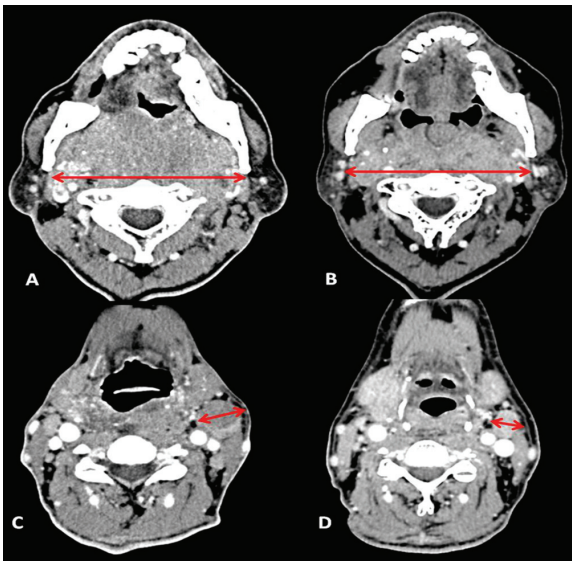

Fig. 2 Measurement of target lesions according to RECIST guideline. A and C are pre-treatment CECT, B and D are post-treatment CECT. A and B show measurement of the primary tumor using largest diameters, whereas C and D show measurement of the pathologic nodes using minimal transverse diameters.

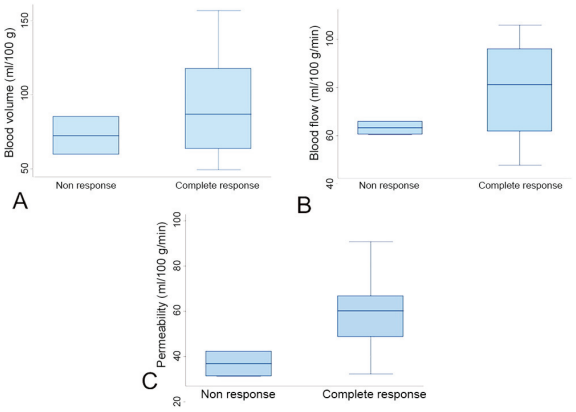

Fig. 3 Box plot comparing perfusion parameters between "Non-response" group and "Complete response" group. A) blood volume, B) blood flow, C) permeability.

characteristic (ROC) curve analysis was performed on the basis of logistic regression model to determine the single best CTP parameter in regard to ability to differentiate "Complete response" group from "Non-response" group. All statistical analyses were performed using stata 11.1 (Stata, College Station, Texas, USA), and p-value <0.05 was considered to indicate a statistically significant difference.

Results

Among the 12 patients, ten (83.3%) of them were complete response, belonging to "Complete response" group, whereas one of them with stable disease and another one with progressive disease (16.7%) belonged to "Non-response" group. Six patients received post-treatment biopsy with histological proof of no residual malignancy to confirm complete response status. Table 2 summarizes mean and SD of CTP parameter values in each group. Pearson's correlation coefficient (r) demonstrated that all CTP parameters including BV, BF, and permeability had a positive correlation with the degree of primary tumor volume reduction. The permeability had a strongest correlation with a correlation coefficient equal to 0.494 (p = 0.103). The BF had a stronger correlation to % primary tumor volume reduction (r = 0.279, p = 0.380) than BV that had a weak correlation (r = 0.095, p = 0.770). None of these parameters had a statistically significant correlation with % tumor volume reduction.

The boxplots (Fig. 3) of CTP parameters show that values of all parameters had trend to be higher in "Complete response" group compared than "Non-response" group. The distribution of permeability values in "Complete response" group was more tightly clustered without overlap than in "Non-response" group. The BV had a largest overlapping value among these parameters. Using Mann-Whitney U test, there were no statistically significant difference in mean BV, BF and permeability values between "Complete response" group and "Non-response" group with p-values of BV, BF, and permeability equal to 0.519, 0.390, and 0.053 respectively. However, the p-value of the permeability was almost significant.

The logistic regression model using permeability for predicting response to treatment had an area under ROC curve (AUC) of 0.95 (95% CI = 0.81-1.00) (Fig. 4). Therefore, the permeability was an

Table 2. Mean (SD) CTP parameter values in complete response and non-response groups

	Complete response (n = 10)	Non-response (n = 2)	p-value
BV	92.3 (34.7)	72.5 (18.2)	0.519
BF	78.4 (21.3)	63.2 (3.9)	0.390
Permeability	58.7 (21.3)	36.9 (7.8)	0.053

CTP = CT perfusion; BV = blood volume; BF = blood flow

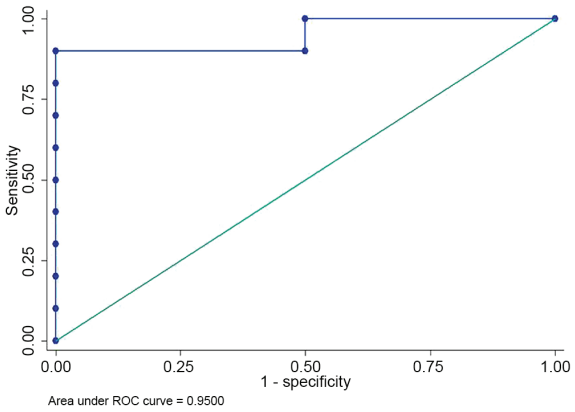

Fig. 4 Area under ROC curve of the permeability. AUC: 0.9-1.0 = excellent, 0.8-0.9 = good, 0.7-0.8 = fair, 0.6-0.7 = poor, 0.5-0.6 = fail

excellent CTP parameter to discriminate between "Complete response" group and "Non-response" group with optimal cutoff value of 45 ml/100 g/min, which showed 100% and 90% sensitivity and specificity, respectively. BF was a fair parameter with AUC of 0.70 (95% CI = 0.37-1.00), whereas BV was a poor parameter with AUC of 0.65 (95% CI = 0.26-1.00).

Discussion

Oxygen is known to be a radiosensitizer. It enhances the formation of free radicals and draws it into the chain reactions of enhancing cell death from ionizing radiation. An imbalance between oxygen supply and consumption, largely resulting from the presence of inadequate and heterogeneous vascular networks, leads to tumor hypoxia. Nordsmark et al[9,10] showed that pre-treatment tumor oxygenation status is correlated to the tumor control in the advanced head and neck squamous cell carcinoma treated by radiation therapy. The most hypoxic tumor is related to the poor tumor control probability. Manipulation of the hypoxic state during therapy results in improved treatment response[11]. Direct measurement of oxygenation status using oxygen-sensitive needle electrodes has been performed in animal tumors and in certain human tumors. This technique is invasive and not practical in a certain clinical setting, especially considering the limited accessibility of the nasopharynx. A non-invasive method for quantification of tumor oxygenation is therefore warranted.

Tumor perfusion and tumor oxygen concentration are factors that are usually strongly linked, although tumor oxygenation depends also oxygen consumption by the tumor cells. The oxygen availability or oxygen supply is the amount of oxygen carried by the blood to a given tissue per unit of time; it is the product of the perfusion rate and the arterial oxygen concentration[12]. Various modalities of indirect oxygenation measurement have been implemented, including positron emission tomography (PET), MR perfusion (MRP), and CTP. The use of PET is limited by availability and cost. MRP is advantageous in that the patient is not exposed to ionizing radiation and a contrast agent may not be required, depending on the protocol used[13].

Deconvolution-based CTP is an imaging technique that can allow calculation of parametric maps for regional BV, BF, and permeability. Determination of tissue perfusion is based on examining the relationship between arterial, tissue, and venous enhancement after the administration of an intravenous bolus of contrast material. Repeated rapid CT scans at a specified location are performed to allow construction of a time-attenuation curve. This is assuming that attenuation is directly proportional to concentration of contrast material. Images are obtained as the contrast material washes into and out of the tissue[14]. Contrast agents exhibit two-compartment pharmacokinetics, i.e., there are intravascular and extravascular components. In the intravascular phase of enhancement, BF, and BV values can be measured, whereas permeability of capillaries is evaluated in the extravascular phase. Elevated values of these parameters within the tumors are the result of development of neovascularization that is essential for the growth of the tumor, known as angiogenesis, identified by angiography and histology analysis[15-17]. The tumor blood vessels are usually abnormally permeable to circulating molecules, including contrast material. The degree of tumoral angiogenesis is critical in assessing tumor grade and tumor progression or recurrence. Ash et al[18] demonstrated a positive but not statistically significant correlation between CTP parameters (BV and BF) and intratumoral microvessel density (MVD) of endoscopic biopsy specimens obtained from squamous cell carcinoma of head and neck, which had been the quantified parameter of the tumor angiogenesis. It has been postulated that higher intratumoral MVD reflected increased oxygenation and subsequently was able to be a marker for responsiveness of tumors to radiation and/or chemotherapy. Thus, BV and BF could be surrogate markers for tumor oxygenation. Zima A et al[19] also demonstrated that elevations of BV and BF are statistically correlated with better oxygenation and

local delivery of chemotherapeutic agents to the primary tumor and may be useful in predicting response to induction of chemotherapy.

In the present study, even if there were no statistically significant correlation there would be a trend of positive correlation between higher pre-treatment BF and degree of primary tumor volume reduction with correlation coefficient of 0.279, whereas there was a relatively weak positive correlation of BV with correlation coefficient of 0.095. The result of the present study was contradicting to the preliminary study of Gandhi et al[20] who showed a statistically significant correlation between higher pre-treatment BV and primary tumor volume reduction as assessed by endoscopy comparing prior to and after induction of chemotherapy in advanced squamous cell carcinomas of the oropharynx. According to RECIST criteria, the present study supported trend of higher values of BV and BF in "Complete response" group. In comparison with BV, BF had a stronger correlation with less overlapping value. However, there was no statistically significant difference between these CTP parameter values in "Complete response" group and "Non-response" group.

Regarding permeability, there was a strongest positive correlation between higher pre-treatment permeability and degree of primary tumor volume reduction with a correlation coefficient of 0.494, but this was not statistically significant difference. The box plot was also in line with the trend of higher value of permeability in "Complete response" group without overlapping values. There was also no statistically significant difference in values between "Complete response" group and "Non-response" groups, (p-value = 0.053). Nevertheless, it was nearly significant. The physiologic basis to explain the reason in head and neck malignant tumor is still unclear. Jain et al[21] demonstrated that BV has a significant in vivo correlation with MVD, whereas there is a significant correlation with microvascular cellular proliferation (MVCP) and permeability in the brain glioma as assessed by image-guided biopsy specimens. MVD indicates total tumor vasculature, including both mature and immature vessels in the tumor, whereas MVCP indicates immature tumor vasculature. The region with immature vasculature has been shown to be associated with insufficient blood flow and oxygen transportation, resulting in tumor hypoxia. Permeability value in CTP parameter is a measure of a microvascular capillary permeability to a variety of micro- and macromolecules within the tumor. Increased endothelial permeability may affect degree of local delivery of chemotherapeutic agents. Tumor with higher permeability may receive higher local dose due to increased diffusivity of therapeutic agent as the result of leakiness of the capillary endothelial membranes. Thus, one may be able to predict response of chemotherapy on quantitative permeability measurement. Most of the patients (10 of 12 patients, 83.3%) in the present study received concurrent chemo-radiotherapy. Higher value of permeability was detected in "Complete response" group and ROC analysis was used to identify that permeability had been a single best CTP parameter to differentiate between "Complete response" group and "Non-response" group. Thus, the authors hypothesized a similar association between permeability and responsiveness of NPC to chemotherapy as observed in cerebral glioma. The study of Zima et al[19] also supported trend that higher value of permeability correlates with favorable response to induction chemotherapy in advanced squamous cell carcinoma at various locations of upper aerodigestive tract.

The present study had a few number of limitations. Not all patients with NPC had pre-treatment CT imaging at our institution and six patients with pre-treatment CECT and CTP refused to perform post-treatment imaging in the present study, thus causing small size of the patient population. It was conceivable that trend to elevated CTP parameter values predicting response to chemo-radiotherapy may turn out to be statistically significant with further study of larger patient population. A prospective multi-institutional study is required to validate the results. Finally, the patient population is heterogeneous concerning the TNM stadium, and this is probably a confounding factor for the therapy results.

Conclusion

In general, direct nasopharyngoscope with biopsy is the gold standard for assessing tumor response. This procedure is invasive. The present study demonstrated that higher values of pre-treatment permeability and BF had trend to be strongly correlated with better response of the nasopharyngeal carcinoma to concurrent chemo-radiotherapy without statistical significance. Change of various CTP parameter values reflects different physiological processes. Pre-treatment permeability was the excellent CTP parameter to differentiate between "Complete response" group and "Non-response" group, and may potentially be a noninvasive technique in predicting

treatment response. Manipulation of tumor oxygenation status during therapy in the patients with low pre-treatment BF and permeability values may result in improved treatment response.

What is already known on this topic?

Nasopharyngeal carcinoma (NPC) is uncommon in western nations. It is the most common head and neck cancer in Thailand. Diagnosis of NPC is based on clinical and radiological examination and verified histologically by biopsy. Radiotherapy with or without chemotherapy are the primary treatment modality. Direct nasopharyngoscope with biopsy is the gold standard for assessing tumor response. This procedure is invasive with risk of hemorrhage or infection. CT perfusion (CTP) is an imaging technique that can assess physiologic parameters such as blood volume (BV), blood flow (BF), mean transit time (MTT), and capillary permeability surface area product (CP). The previous study demonstrated that pretreatment BV and BF were statistically associated with response to induction chemotherapy in advanced stage SCC of another upper aerodigestive tract. Pretreatment CTP to assess responsiveness in NPC treated by radiotherapy with or without chemotherapy has not been reported.

What this study add?

The patients with isolated histological proved NPC were enrolled. CTP can be incorporated into the routine CT protocols. The present study demonstrated that all CTP parameters including BV, BF, and permeability had a positive correlation with the degree of primary tumor volume reduction without statistical significance. In addition, all parameters had a trend to be higher in "Complete response" group compared with "Non-response" group. The logistic regression model using permeability for predicting response to treatment had an area under ROC curve (AUC) of 0.95. The permeability was an excellent CTP parameter to discriminate between "Complete response" group and "Non-response" group with optimal cutoff value of 45 ml/100 g/min, which showed 100% and 90% sensitivity and specificity, respectively.

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Potential conflicts of interest

None.

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การทำนายผลการรักษามะเร็งช่องคอหลังโพรงจมูกโดยใช้เทคนิคการตรวจเลือดที่หล่อเลี้ยงมะเร็งของการตรวจด้วยเครื่องเอกซเรย์คอมพิวเตอร์

โลจนา ตันติยาทร, เอกพงษ์ ฟูสุวรรณกายะ, ธิติ สว่างศิลป์, ธงชัย พงศ์มฆพัฒน์

ภูมิหลัง: *การตรวจโดยการส่องกล้องและตัดชิ้นเนื้อเพื่อตรวจทางพยาธิวิทยาเป็นการตรวจมาตรฐานในการประเมินผลการรักษามะเร็งช่องคอหลังโพรงจมูก แต่การตรวจนี้มีความเสี่ยงจากภาวะเลือดออกและการติดเชื้อ*

วัตถุประสงค์: *เพื่อศึกษาประโยชน์ของการใช้เทคนิคการตรวจเลือดที่หล่อเลี้ยงมะเร็งของการตรวจด้วยเครื่องเอกซเรย์คอมพิวเตอร์และหาตัวแปรที่ใช้ทำนายผลการรักษา*

วัสดุและวิธีการ: *ได้ทำการศึกษาผู้ป่วยจำนวน 12 ราย ที่ผลทางพยาธิวิทยายืนยันว่าเป็นมะเร็งช่องคอหลังโพรงจมูก ทุกรายได้รับการตรวจด้วยเครื่องเอกซเรย์คอมพิวเตอร์แบบฉีดสารทึบรังสี และทำการตรวจเพิ่มด้วย CT perfusion ซึ่งเป็นการตรวจภาวะเลือดที่หล่อเลี้ยงก้อนมะเร็ง ก่อนให้การรักษาด้วยการฉายแสงหรือการฉายแสงร่วมกับเคมีบำบัด จากนั้นนำข้อมูลมาสร้างภาพและวัดค่า blood flow, blood volume และ permeability ทำการตรวจซ้ำด้วยเครื่องเอกซเรย์คอมพิวเตอร์แบบฉีดสารทึบรังสี หลังจากครบกำหนดการรักษาภายใน 3 เดือน ทำการวัดปริมาตรของก้อนมะเร็งก่อนและหลังรักษาเพื่อนำมาเปรียบเทียบกัน และการประเมินการตอบสนองผลการรักษาตามแบบของ RECIST โดยนำผลบวกของความยาวของเส้นผ่าศูนย์กลางที่ยาวที่สุดของก้อนเนื้อมะเร็งกับความยาวของต่อมน้ำเหลืองในด้านตัดขวางจากภาพเอกซเรย์คอมพิวเตอร์ก่อนและหลังการรักษาเพื่อแบ่งกลุ่มผู้ป่วยแบบกลุ่มตอบสนองและกลุ่มที่ไม่ตอบสนองต่อการรักษา การวิเคราะห์ทางสถิติใช้ Pearson และ Mann-Whitney U Test*

ผลการศึกษา: *จากการศึกษามีผู้ป่วยที่ตอบสนองต่อการรักษา 10 ราย (83.3%) และไม่ตอบสนอง 2 ราย (16.7%) การเพิ่มขึ้นของค่า permeability, BF, BV มีความสัมพันธ์เชิงบวกกับอัตราการลดปริมาตรของก้อนมะเร็งและการตอบสนองต่อผลการรักษา (p = 0.053, 0.390, และ 0.519 ตามลำดับ) ตัวแปรที่ใช้แยกระหว่างกลุ่มตอบสนองและไม่ตอบสนองได้ดีที่สุด คือ permeability โดยมีพื้นที่ใต้กราฟ ROC เท่ากับ 0.95 ค่าที่ใช้แยกที่เหมาะสมเท่ากับ 45 มิลลิลิตร/100 กรัม/นาที (ความไว 100%, ความจำเพาะ 90%)*

สรุป: *เทคนิคการตรวจเลือดที่หล่อเลี้ยงมะเร็งช่องคอหลังโพรงจมูกก่อนการรักษาช่วยในการทำนายผลการตอบสนองต่อการรักษา ค่า permeability เป็นตัวชี้วัดที่ดีที่สุดในการแยกกลุ่มเนื่องจากมีความไวสูงสุด*