Comparison Of Homogeneity Indices For Quantitative Evaluation Of Dose Homogeneity For IMRT Treatments Of Head And Neck Cancers

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Abstract

The purpose of this study was to evaluate different homogeneity indices for IMRT of head and neck cancers and to suggest the best representative homogeneity index for quantitative measure of dose homogeneity.

In this study 3 different homogeneity indices were evaluated for 22 head and neck cancer patients receiving dynamic IMRT treatments on Clinac-DHX linear accelerator with 6 MV photon beam. IMRT planning was carried out with Helios software on Eclipse treatment planning system. H index, HI index and S index proposed by Yoon (2007) were calculated for these patients.

The H-index, HI index and S index values varied between 1.024 to 1.112, 4.03 to 16.9 and 0.94 to 3.43 respectively. H index values for patient 5 and 10 are identical (H index-1.06) though different in DVH distributions but the S index values for these patients are different (1.36 and 2.01). Similarly the HI index for the patient 11 and 16 are identical in spite of different DVH distributions but S index values are different for patient 11 and 16. Since the S index represents the whole DVH curve unlike the conventional indices which depends on dose at a point, it is the better method to quantify the dose homogeneity. These results indicate that H and HI indices do not provide the accurate dose homogeneity information, but the S indices uniquely provide quantitative information about the dose homogeneity.

Keywords

Homogeneity Index, IMRT, Head and Neck cancer, Dose Homogeneity

Introduction

Intensity modulated radiotherapy (IMRT) is currently implemented in clinical use all over the world. Basic and clinical research work shows that IMRT dose distributions are highly conformal and complex[1-5]. While the power of IMRT is to confirm the high dose volume to the target and spare adjacent normal structures, dose distributions of IMRT plans are typically much more heterogeneous than those of conventional 3D derived plans[6-7]. Comparing competing IMRT plans becomes the challenging process.

Display of dose distribution in the form of isodose curves or surfaces is useful not only because it shows regions of uniform dose, high dose, or low dose but also their anatomic location and extent. In 3-D treatment planning, this information is essential but should be supplemented by dose-volume histograms (DVH) for the segmented structures, for example, targets, critical structures, etc. A DVH not only provides quantitative information with regard to how much dose is absorbed in how much volume but also summarizes the entire dose distribution into a single curve for each anatomic structure of interest. It is, therefore, a great tool for evaluating a given plan or comparing competing plans.

The DVH may be represented in two forms: the cumulative integral DVH and the differential DVH. The cumulative DVH is a plot of the volume of a given structure receiving a certain dose or higher as a function of dose. Any point on the cumulative DVH curve shows the volume that receives the indicated dose or higher. The differential DVH is a plot of volume receiving

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a dose within a specified dose interval (or dose bin) as a function of dose. Of the two forms of DVH, the cumulative DVH has been found to be more useful and is more commonly used than the differential form. The DVH is thus a powerful tool for summarizing and qualifying complex dose distributions. One of the most important benefits of a DVH is that it provides an accurate assessment of homogeneity in the PTV. The presence of cold spots in a dose distribution will negatively affect the tumor control and accurate evaluation of homogeneity in the PTV is therefore essential to the efficacy of the treatment plan. The purpose of this study was to evaluate different homogeneity indices for IMRT of head and neck cancers and to suggest the best representative homogeneity index for quantitative measure of dose homogeneity.

Materials and Methods

In this study three different homogeneity indices were evaluated for twenty-two head and neck cancer patients receiving dynamic IMRT treatments on Clinac-DHX linear accelerator with 6 MV photon beam. IMRT planning was carried out with Helios software on Eclipse treatment planning system. These patients received IMRT treatments with 5 to 7 fields. The conventionally used homogeneity index (H-index) is defined as the ratio of the maximum dose (D_{max}) in the PTV to the prescribed dose (D_p)[8-10].

In addition to the H index, another homogeneity index called as HI index has been defined as [11]:

$$HI = ((D_2 - D_{98})/D_p) \times 100\%$$

Where D2 and D98 represents the doses to 2% and 98% of the PTV respectively. For example D98 indicates that at least 98% of the target volume receives this dose, and hence D_2 and D_{98} are considered to be the maximum and minimum doses respectively. So lower HI values indicates a more homogeneous target dose. The new homogeneity index called as 'S' index (Sigma index) proposed by Yoon (2007) is defined as the standard deviation of the normalized differential dvh curve [12]:

$$S\text{- Index} = D_{SD} = \sqrt{[\Sigma (D_i - D_{mean})^2 \times v_i/V]}$$

Where D_{SD} represents the standard deviation of the dose, v_i is the ith volume element receiving a dose of at least (D_i) and V is the total volume, Dmean is the mean dose.

Results

To investigate how the conventionally used homogeneity indices (H index and HI index) related to the S-index, we analyzed data from 22 head and neck cancer patients at our institution. Table 1 indicates that as S index values increases

Patient	H index	HI	S index
1	1.037	4.08	0.94
2	1.029	4.43	1.03
3	1.024	4.03	1.06
4	1.046	5.53	1.31
5	1.060	6.20	1.36
6	1.076	5.61	1.40
7	1.073	9.51	1.47
8	1.047	6.89	1.55
9	1.050	7.74	1.89
10	1.060	8.57	2.01
11	1.063	8.93	2.06
12	1.052	8.82	2.08
13	1.057	9.08	2.14
14	1.068	9.06	2.15
15	1.073	8.47	2.26
16	1.087	8.93	2.34
17	1.051	9.81	2.36
18	1.075	12.9	2.76
19	1.112	13.5	2.81
20	1.094	13.2	2.95
21	1.092	12.5	2.96
22	1.069	16.9	3.43

Table 1: List of different homogeneity indices as sorted by S index

the HI index values also increases. However, some exceptions seen, in that HI index can provide in correct dose homogeneity information. The H indices and S indices values were not matched as well.

To investigate how the H index values are related to the S index values, we compared a pair of patient's (5 and10) DVHs for head and neck tumors shown in Fig. 1(a) and 1(b). Fig. 1(a) shows cases in which the DVH curves are quite different but H indices values are similar (both H index – 1.06). The dose homogeneity of the DVH clearly indicates that Patient 5 is better than patient 10. Since the H index values are based on ratio of the dose at two points in the DVH, there is a difference between the DVHs though the H index values are same. Fig. 1(b) shows the normalized DVH curves for the patient 5 and patient 10. The S index values of the patient 5 and patient 10 is 1.36 and 2.01 respectively. Since the S index values are representation of whole DVH it clearly indicates that dose homogeneity of patient 5 is better than patient 10.

Similarly HI index and S index also compared between a pair of patients. Fig. 2(a) shows that the HI values for patient 11 and patient 16 were identical (HI index- 8.93) and do not accurately represent dose homogeneity and from the DVH it is clear that the dose homogeneity for patient 11 is better than patient 16. Fig. 2(b) shows that the S indices are 2.06 and 2.34 for patient 11 and patient 16 respectively. The patient 11 DVH is better than the patient 16's DVH which indicates that the S index provides quantitative accurate information on the dose homogeneity.

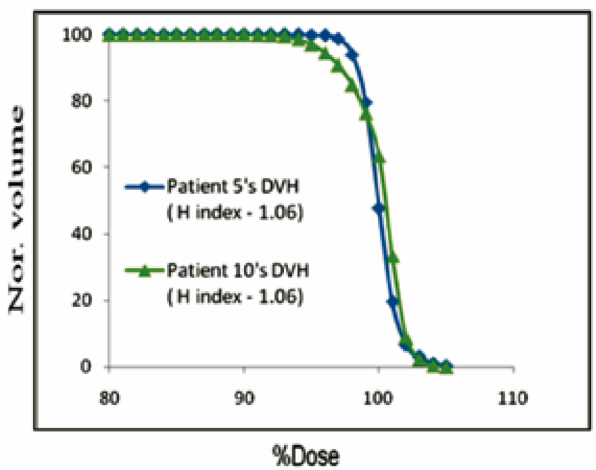

Fig. 1(a): Cumulative dose volume histograms of patient 5 and 10 with their corresponding H index values.

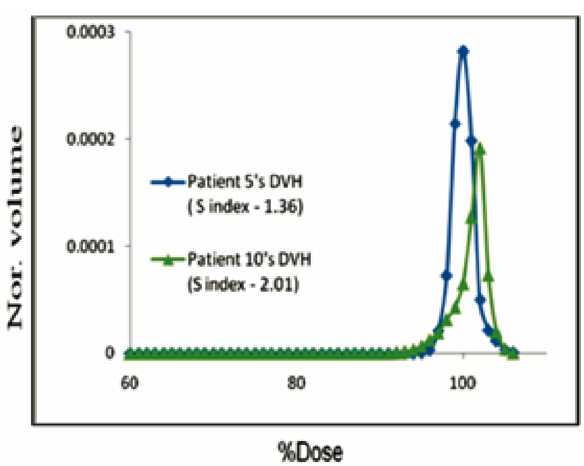

Fig. 1 (b): Differential dose volume histograms of patient 5 and 10 with their corresponding S indices values.

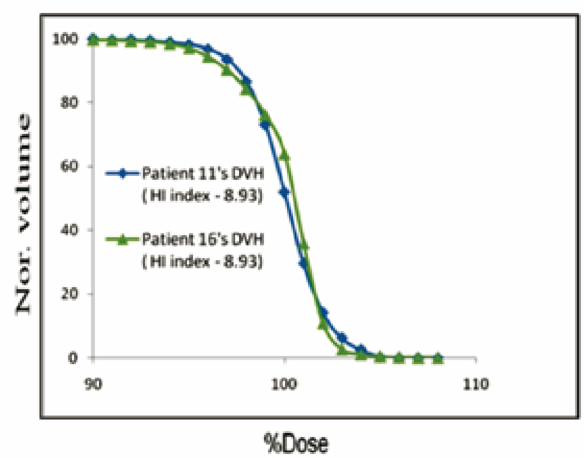

Fig. 2(a): Cumulative dose volume histograms of patient 11 and 16 with their corresponding HI indices values.

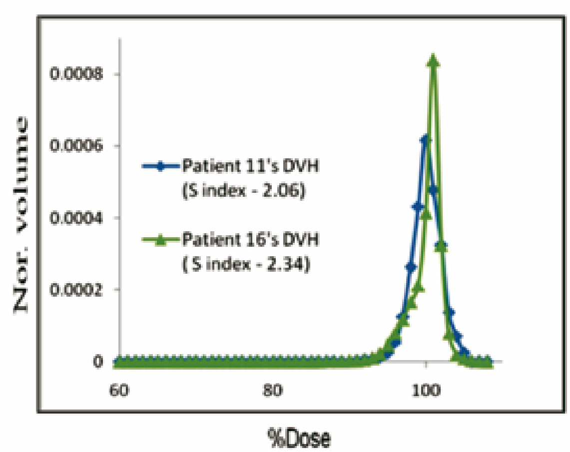

Fig. 2(b): Differential dose volume histograms of patient 11 and 16 with their corresponding. S indices values.

Fig. 3(a) shows cases in which H index values and HI index values are indeed different. H index and HI index values are 1.094, 13.2 and 1.092, 12.5 for patient 20 and 21 respectively. But the DVH curves clearly indicate that dose homogeneity of the patient 20 and 21 are similar. The S index values in Fig. 3(b) are nearly equal (S-index – 2.96 and 2.95) and accurately representing the dose homogeneity while there is no such difference in DVH distributions.

Similarly in Fig. 4 (a) the different H index and HI index values were compared with S index values. The H index and HI index values are 1.057, 9.08 and 1.068, 9.06 for the patient 13 and patient 14 respectively. The DVHs distributions show that there is similar dose homogeneity between the two patients but there is actually a difference in H index and HI index values. Fig. 4(b) clearly indicates that the S index values for the two patients are the same (S index – 2.14 and 2.15 for patient 13 and patient 14 respectively) which indicate that there is not much difference between the dose homogeneity between the patients.

The conventional homogeneity indices can be improved by modifying their definition. We compared the modified H index and modified HI index instead of H index and HI index with S index as proposed by Yoon (2007). The modified H index is defined as the ratio of D5 (instead of Dmax in the case of H index) to the DP. In the modified HI index, we used D5 and D95 instead

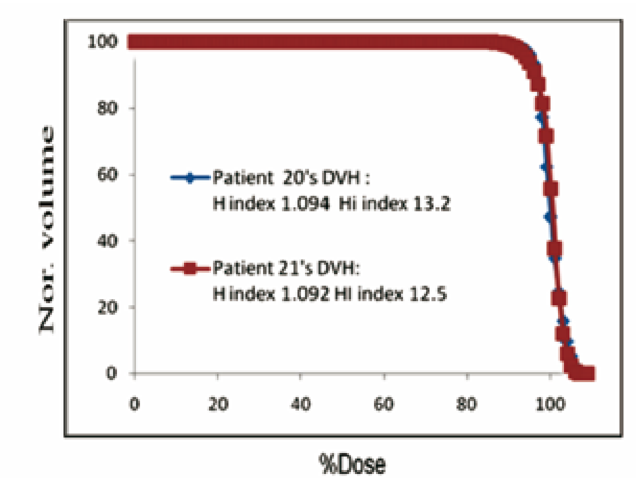

Fig. 3(a): Cumulative dose volume histograms of patient 20 and 21 with their corresponding. H indices and HI indices values.

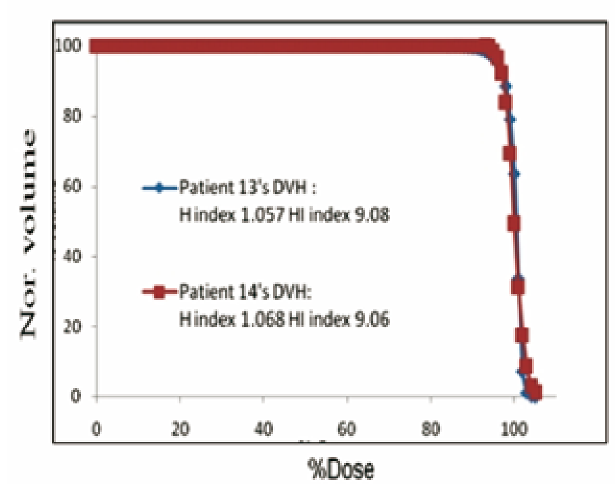

Fig. 4(a): Cumulative dose volume histograms of patient 13 and 14 with their corresponding. H indices and HI indices values.

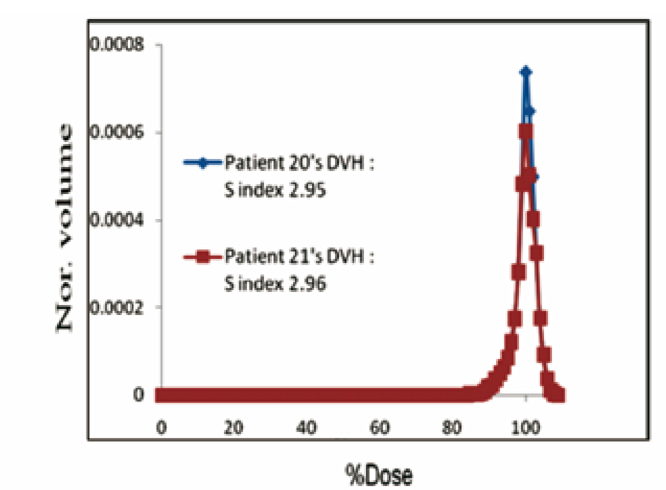

Fig. 3(b): Differential dose volume histograms of patient 20 and 21 with their corresponding. S indices values.

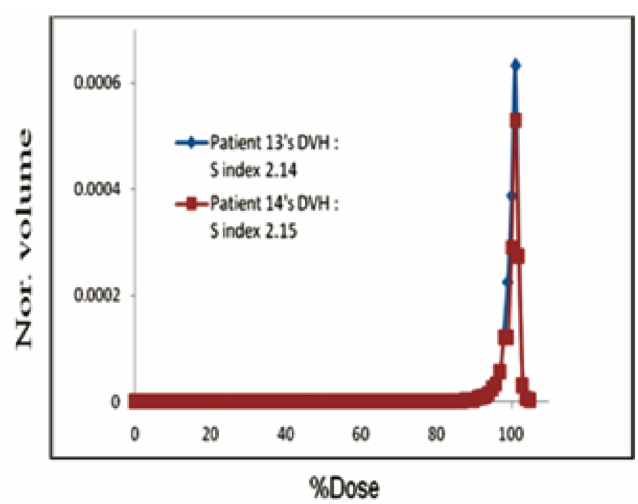

Fig. 4(b): Differential dose volume histograms of patient 13 and 14 with their corresponding S indices values

of D2 and D98. By using the modified H index and HI index, the conventional homogeneity index can be improved to provide accurate quantitative homogeneity information to evaluate the treatment plans. To investigate how modified H index (mH) and modified HI(mHI) index improving the dose homogeneity, we calculated the mH index and mHI index values for the patient 5 and 10 and also for the patient 11 and 16. Fig. 5(a) shows that the modified H index values are 1.023 and 1.025 and the dose homogeneity of patient 5 is better than patient 10. Similarly the modified HI index values of patients 11 and 16 were 6.6 and 6.8 respectively as shown in Fig. 5(b). As shown in Fig. 5(a) and 5(b) it is clear that by using modified H and HI indices instead of H and HI homogeneity indices will improve the quantitative dose homogeneity information in evaluating the treatment plans.

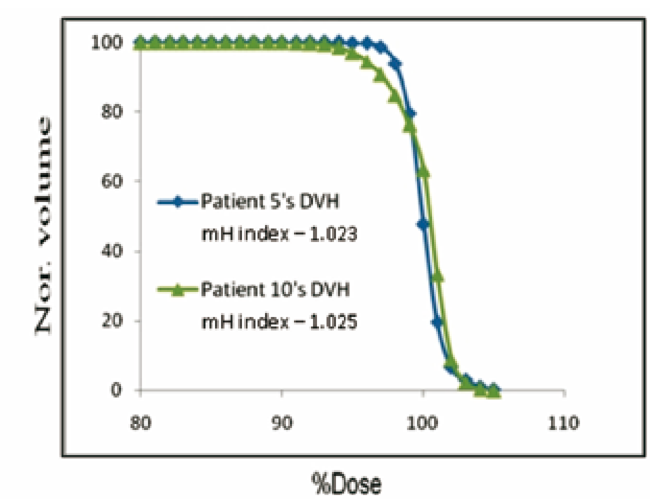

Fig. 5(a): Cumulative dose volume histograms of patient 5 and 10 with their corresponding modified H indices values.

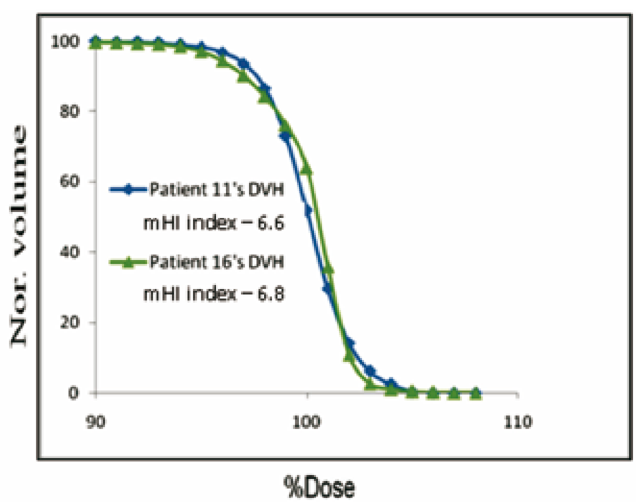

Fig. 5(b): Cumulative dose volume histograms of patient 11 and 16 with their corresponding modified HI indices values.

Discussion

The variations in homogeneity values calculated in target volume between conventional homogeneity indices and "S" index is that the conventional homogeneity index defined is based on few points in DVH. But the S index is based on the values from the entire DVH rather than few points in DVH. From Fig. 1(a) and 1(b), the H index does not clarify the difference between the DVHs of patient 5 and 10. But the difference in S index clearly indicates that the homogeneity of PTV of dose of patient 5 is about 47% better than patient 10. Similarly, from Fig. 2(a) and 2(b), it is clear that the HI index indicates that the homogeneity of the two DVHs is the same, which contradicts the better homogeneity of the DVH of patient 11 as compared with that of patient 16. This result shows that, like the H-index, the HI method can give incorrect information about dose homogeneity. Fig. 2(b) indicates that, based on the S-index, the dose homogeneity of the DVH is 14 % better for patient 11 than for patient 16, which indicates that the S-index uniquely provides quantitatively accurate information on dose homogeneity. In Fig. 5(a), small difference in modified H index (1.023 and 1.025) between patient 5 and 10 shows that the conventional homogeneity indices can be improved by modifying their definition. Similarly 0.2 (6.6 and 6.8) difference in modified HI index in Fig. 5(b) shows that the homogeneity for patient 11 is better than patient 16. This study clearly indicates that any homogeneity index based on the doses at only a limited number of points of the DVH may provide incorrect information about dose homogeneity in the PTV.

We investigated the three different homogeneity indices namely H index, HI index and S index. Our findings are in good agreement with the findings of Yoon (2007). The new homogeneity index ('S' index) is better than the conventional H and HI indices in providing the quantitative information on the dose homogeneity in IMRT treatments of head and neck cancers.

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