Development of head docking device for linac-based radiosurgery with a Neptun 10 PC linac

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Abstract

Stereotactic radiosurgery is a method for focused irradiation of intracranial lesions. Linac-based radiosurgery is currently performed by two techniques: couch mounted and pedestal mounted. In the first technique a device is required to affix the patient's head to the couch and moreover to translate it accurately. Structure of such a device constructed by the authors plus acceptance test performed for evaluation is described in the article.

A head docking device has been designed and constructed according to geometry of linac's couch and also desired functions. The device is completely made from aluminum and consists of four major components: attachment bar, lower structure with four movements, upper structure with two movements equipped with a lock, two handles and a mounting ring for stereotactic frame. Translating accuracy, mechanical stability and isocentric accuracy were assessed in the frame of acceptance test.

Translating accuracy, mechanical stability and isocentric accuracy were found to be respectively: 1 mm, 1.64 mm and 3.2 mm with accuracy of 95%.

According to AAPM report no.54, a head docking device should translate head with an accuracy of 1 mm; this recommendation has been met. Moreover, we have demonstrated that the isocentric accuracy and mechanical stability of the device are sufficient that the device can confidently be used in stereotactic treatment.

KEYWORDS: Stereotactic radiosurgery, Head docking device, Translating accuracy, Mechanical stability.

1. Introduction

Stereotactic radiosurgery with external irradiation is an important method for treating arteriovenous malformation [1], malignant and benign primary tumors and single metastasis [2, 3].The method was initially introduced by Swedish neurosurgeon Lars Leksell [4].

A high radiation dose is delivered to stereotactically localized lesion, either in single session (SRS) or in multiple sessions (SRT), while sparing normal surrounding tissue.

The use of linear accelerators in radiosurgery was first proposed theoretically by Larsson et al in 1974. The first reports on clinical linac-based radiosurgery were published 10 years later in 1984 by Betti and Derechinsky and in 1985 by Colombo *et alii* and Hartman *et alii* [5, 6, 7].

A number of different patient positions have been used for radiosurgery with linac-based stereotactic units. The patient could be either in a sitting or lying position while the patient support system could be either chair [8], pedestal [9] or couch-mounted. These systems differ by means of mechanical accuracy during the treatments. Among the above mentioned systems the first is no longer used and the second due to probability of collision between gantry and couch for posterior arcs is currently less considered practically.

Nowadays couch-mounted systems are considered superior, providing more freedom for choosing the arc length as well as the beam portals. On the other hand, the mechanical accuracy of the system is strongly dependent on the inherent rotational accuracy of the treatment couch, thus not all linacs are appropriate for such a system [10]. The chosen devices for setting up SRS/T depend on type of system, mechanical properties of linac, imaging modality and treatment team tendency.

A couch-mounted system was selected for starting stereotactic treatment in Imam Reza hospital and designing of needed hardware was performed considering accepted pattern for such devices.

One of the essential requirements in a couch-mounted system is a device affixing patient's head to treatment couch and also possessing the ability to translate and rotate it in three main axes x,y and z (6 degree of freedom) [11].

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Generally the major translation is provided by couch motors and the minors by driving system of docking device. Moreover this device has to fix the frame attached to patient's head, invasively or non invasively, to couch and avoiding any movement during treatment.

2. Material and Methods

Except the part attached to linac's couch, the head docking device is made from aluminum and composed of 67 pieces. AutoCAD software was used to design the pieces based on needed movements, functions and more importantly geometry of used linac's couch. Head docking device is composed of following major components:

A: Couch attachment bar.

B: Lower structure with four movements.

C: U-shaped upper structure with two movements, equipped with one locking system and two handles.

D: Mounting ring for stereotactic frame.

2. 1. *Couch attachment bar*

Is the only part of device which is made from steel and its dimension has to be according to dimensions of linac's couch. It is fixed to the couch by means of two tapering rods inserted in two canals at the ends of couch (Figure 1).

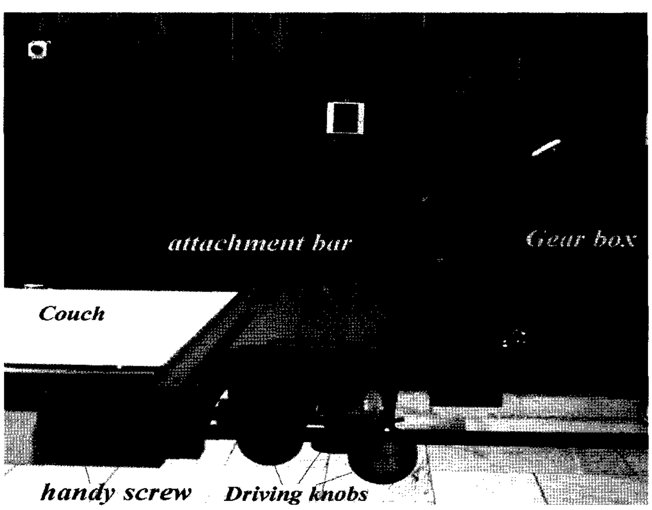

Fig. 1. Lateral view of head docking device attached to linac's couch.

2. 2. *Lower structure*

This is directly connected to attachment bar providing two linear translation in direction of x and y axes and two rotation around y and z axes. Linear translation systems are composed of a driving screw and motion guiding device.

Driving screws are connected to their moving parts by means of floating jointers. Precise guiding of translations is provided by so called wagon and rail systems available in market. A driving screw connected by a floating jointer to attachment bar provides angular torque (Figure 2).

Y rotation axis is located at right side of lower structure (Figure 2). This axis connects base plate of y translation system to the block encompassing z rotation system.

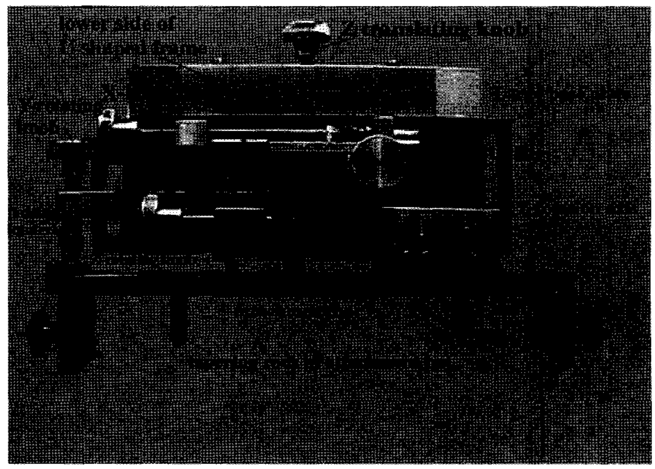

Fig. 2. Posterior view of head docking device showing translating and rotating systems.

2. 3. *Upper structure*

This consists of a U-shaped frame, a gearbox, a large base plate and a linear z translating system. Linear z translating system is composed of a long driving screw and two guiding rods. Mounting ring for stereotactic frame is connected to inner aspect of U-shaped frame through two strong pivots (Figure 3). On the left lateral aspect of U-shaped frame a gearbox is mounted turning mounting ring around x axis.

Moreover there are two handles at opposite lateral sides of large base plate to facilitate transport-

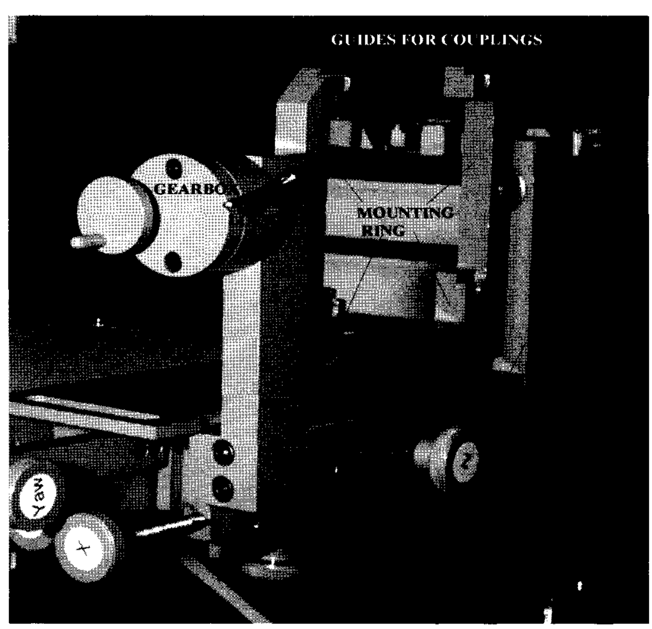

Fig. 3. Left oblique view of head docking device showing mounting ring and gear box.

ing and mounting heavy docking device weighing 15 kg.Range of movement in three x,y and z axes provided by above mentioned parts are 5 cm.

2. 4. *Mounting ring for stereotactic frame*

Similar in shape to a square without front side, which is placed inside of U-shaped frame.There are four cylindrical guides on four corners of ring to be fitted with four couplings protruded from lower aspect of stereotactic frame.

2. 5. *Using head docking device*

The first step of treatment is to attach the stereotactic frame to the patient's head and then taking CT or MRI slices. To deliver treatment, the patient is transported on the treatment couch while stereotactic frame is attached to patient's head. Then four coupling of stereotactic frame is inserted in to four guides at corners of ring to affix patient's head to head docking device (Figure 4).

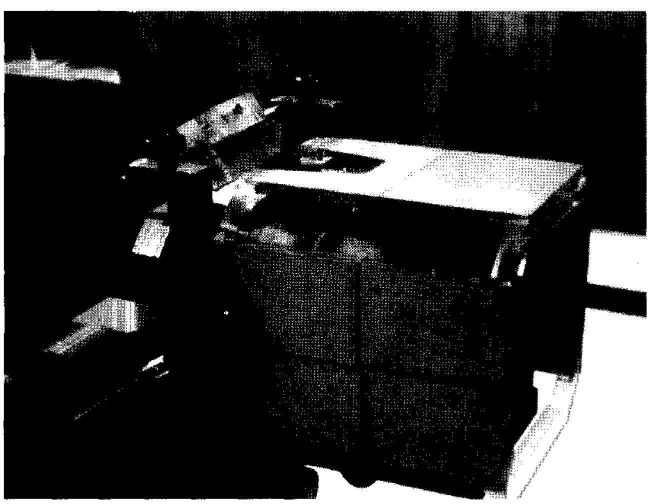

FIG. 4. Centering box placed over non-invasive frame. Stereotactic coordinates are shown on the anterior and lateral plates of the box

As the final step centering box which shows stereotactic reference coordinates is mounted on stereotactic frame. Laser beams of treatment room should necessarily meet each other at linac's isocenter, so by projecting those on coordinates of target shown on the centering box will automatically put treatment target on the isocenter of the linac (Figure 4).

2. 6. *Acceptance test*

Assuring constructed device agrees with established specifications, acceptance test was performed. Acceptance test included translation accuracy, mechanical stability and isocentric accuracy tests.

2. 6. 1. Translation accuracy

The constructed driving system has been designed to provide 1.25 mm translation for each revolving of corresponding driving knob. Moreover plates of centering box are scaled in millimeter. Whether resolution of translation provided by docking device is within ±1 mm was assessed. By observing movement of laser beam on the stereotactic coordinates shown on the centering box, accuracy of translation was evaluated.

2. 6. 2. Mechanical stability

For assessing mechanical stability under normal condition of head weight bearing, a normal weighted person was asked lying on the couch and putting his head on non invasive stereotactic frame attached to docking device. Thereafter centering box was mounted on the frame. Using driving systems of device patient has been translated as far as to project laser beams on 100 coordinates of three stereotactic axes of centering box. This coordinate as the cross point of three main axes could easily be found and taken as origin of movement of laser beam.

At the next step the couch was turned to angles of 0, 45, 90, –45 and –90 degrees and immediately after each turning the couch was returned to zero angle.

Degree of deviation from coordinate of 100 during each couch turning was taken a measure of mechanical stability on each axes.Net displacement of laser beam in stereotactic space and hence docking device was calculated according to following equation:

$$\text{Net displacement of head docking device} = \sqrt{(\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2}$$

Where Δx, Δy and Δz are displacement of laser beam in x, y and z directions, respectively.

It is to be noted that this value is a function of mechanical structure of docking device and more importantly the couch which couldn't be distinguishable from each other regarding the method of assessment.

2. 6. 3. Isocentric accuracy

Smaller intersection of couch, gantry and collimation axes means more accurate treatment.Isocentric accuracy test is most critical check to be accomplished before starting stereotactic treatment [10].

Isocentric accuracy depends to isocentric accuracy of linac and mechanical stability of head docking device. To assess isocentric accuracy a lead ball was placed on mechanical isocenter of linac and thereafter radiographs were taken at different combination of gantry and couch angles using 100 MU irradiation. Distance between centers of lead ball's image and radiation field is a measure of isocentric accuracy.

3. Results

Assessment of translation accuracy showed that the device can readily translate patient's head within 1 mm accuracy. Laser beam thickness is an important limiting factor for getting resolution better than 1 mm. The mechanical stability, as assessed in acceptance test, was found to be 1 ± 0.23 mm (mean ± SD).

Therefore treatment uncertainty due to movement of docking device and couch was 1.64 mm with accuracy of 95% (if normal distribution is assumed).

Average isocenter shift was found to be 1.55 mm with maximum of 2.54 mm and minimum of 0.56 mm (SD= 0.99 mm).Therefore if normal distribution is assumed for individual isocenter shifts then isocentric uncertainty will be less than 3.2 mm (=1.55 +1.65×0.99) 95 % of times.

4. Discussion

One of the most important factors in treatment accuracy especially in couch mounted systems is spatial accuracy of linear accelerator and stereotactic devices[10],which inherent rotation accuracy of gantry and mechanical stability of head docking device and couch contribute to.

According to AAPM report no.54 head docking device must translate the attached stereotactic frame within 1 mm accuracy [10].

Resolution accuracy cannot be assessed to better than 1 mm because of limitations in the measurement technique. Moreover size of grooves of the driving screws of docking device is so to provide resolution of 1.25 mm for each complete revolving of driving knobs. Therefore docking device must easily provide translating resolution of 1 mm by 0.8 of complete revolving, the fact that was verified through objective assessment. Based on above assessment the device agrees well with recommendation of AAPM report no. 54.

Regarding mechanical stability there is no recommended value and the only factor of concern is isocentric accuracy of system which encompasses mechanical stability [13].

Isocentric uncertainty of 3.2 mm means that by extracting mechanical stability (equal to 1.64 mm), rotation accuracy of gantry will be 2.7 mm which is more than that specified by manufacturer.

Measured mechanical stability appears to be resulted more from couch than docking device, which is a direct deduction of results of other researchers [14]. Especially for the used linac (Neptun 10 PC) this factor may be of effectiveness with more probability.

5. Conclusion

A head docking device is one of essential devices for setting up stereotactic radiosurgery technique. The suitability of a device in view of required functions and properties for stereotactic treatment was assessed and verified through acceptance testing. Moreover the results showed the ability of our institution to design and construct modern radiation therapy facilities.

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