Mcnpx Simulation Method for Hand Exposure Patient Using 3d Scanned Model of Object with Free Curved Surfaces

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Abstract - *This study was performed for suggesting a simulation method that can create accurate virtual models of objects with free curved surfaces and perform distortion-free MCNPX simulations. The virtual models acquired by using 3D scan equipment with an accuracy of approximately ±0.025 mm in length, compare with actual objects and are comprised of 11104 polygons. Generally, MCNPX simulations of objects with free curved surfaces are performed through voxelization. In this study, polygon model be tetrahedralized by TetGen for the construction of MCNPX geometry to distortion-free. Then, dose estimation was successfully performed after converting the virtual model into an MCNPX input. With this in mind, a voxelized model was constructed for comparison purposes. The dose estimation functions of the two models were found to be similar, showing a similar amount of computing time by using the mesh tally option with 2e7 histories: for the tetrahedralized model, 729.67 minutes; for the voxelized model, 720.11 minutes.*

I. INTRODUCTION

It is often necessary to perform MCNPX[1] simulations for objects with free curved surfaces when performing a dose estimation with respect to radiation exposure incidents and a precise design at inhomogeneous radiation fields. However, in general, there are two obstacles when it comes to performing such simulations. One is to measure or imitate objects with free curved surfaces, and the other is how to define simulation input mathematically.

First, it is not easy to create an imitation-purpose model for reflecting the shapes and motion characteristics of hands locally exposed to radiation. Even though, the exposed fingers are simplified into a cylindrical shape and phantoms are available[2], they are also difficult due to the numberless detailed measurements required for reflecting the shape and motion characteristics because simplified cylindrical finger cannot reflect original shape, and voxel and polygon phantoms[3,4] are made from fixed human body. Therefore, the simplified cylindrical finger does not reflect various motion characteristic accurately and easily. In this regard, this paper suggests an easier and more accurate imitation method that can directly perform 3D scanning to imitate targets.

Second, though voxelized model simulations have generally been employed for MCNPX simulations of virtual models imitating objects with free curved surfaces, such voxelization processes tend to distort polygon models obtained from the 3D scanning of targets, making simulations of thin imitation object is difficult and generating voxelization effects[5]. For this reason, polygon phantoms are suitable for free curved surface, but it has been developed for Geant[6] system. Therefore, second purpose of this research is a tetrahedralization method for mathematically defining measurements on MCNPX.

II. MATERIAL ANS METHODS

1. Polygon model acquisition and mesh reduction

A piece of Flexscan 3D[7] equipment was used for imitating objects with free curved surfaces The equipment with a single light source and two cameras has an accuracy of ±0.025 mm and the range of scanning time is from 5 to 10 seconds.

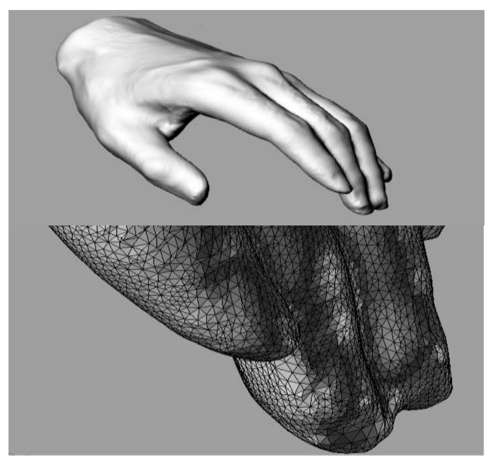

Fig. 1. A polygon model imitating an object with free curved surfaces was produced using a piece of Flexscan 3D equipment (above: the entire hand was rendered; below: a magnified image of the fingertips)

In Fig. 1, a piece of Flexscan 3D equipment was used to imitate a hand touching a radiation source. The corresponding model was comprised of polygons and defined as the inner sides of the sides composed of consecutive 111004 triangles.

MCNPX allows a model to have up to 99,999 surfaces, yet as the corresponding model has the number of the surfaces exceeding the limit, performing an MCNPX simulation of the model is difficult and the number of surfaces should be decreased to a desired level in order to perform tetrahedralization which will be discussed in detail later. This is due to the fact that surfaces in MCNPX do not have ranges. For example, four surfaces are needed to express a triangular surface.

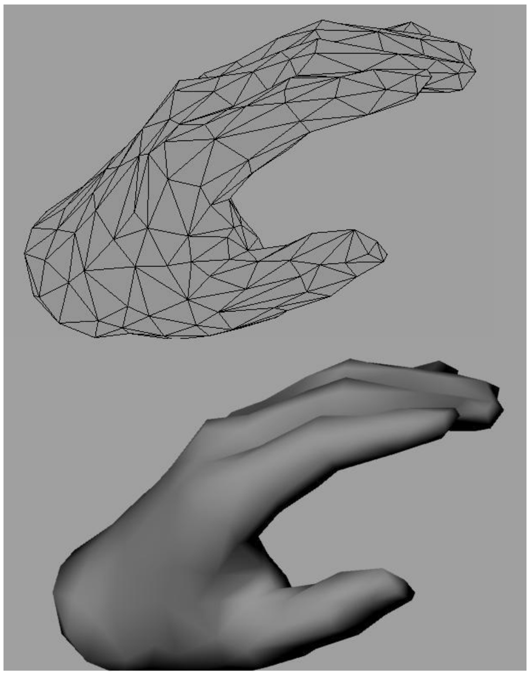

Fig. 2. Polygonal hand model with reduced surfaces (above: an unrendered polygon; below: a rendered polygon)

Fig. 2. above shows an image that has been converted into a model composed of 548 consecutive triangles according to the descriptions above. Such conversion can be performed using the ReduceMesh option of commercial 3D graphic tools or the Optimize option available in such tools. The reason for the sufficient reduction in the number of sides despite the fact that the number of sides can stand at approximately 20,000 even in the event of an increase in the number of sides resulting from the designation of the geometry is to improve the computation time of MCNPX and to facilitate this research.

In terms of precautions for handling a polygon model, whether there are any holes on the polygon model or the polygon is overturned or polygon intrude into other areas should be checked in each process.

2. Tetrahedralizing polygon model

Conventional MCNPX simulation methods are not applicable to polygon models, as it is polyhedron with a large number of sides. However, in this study, simulations in which polygon models are expressed as sets of tetrahedrons are to be performed using the property that all polyhedrons can be expressed as sets of tetrahedrons in which all polygons can be expressed as sets of triangles.

For tetrahedralization, a program called “TetGen”[8] can be used for converting a polygon model into a set of tetrahedrons in a short time. However, as TetGen only supports specific polygon formats, a specific process of conversion into the PLY format is required using a commercial 3D program.

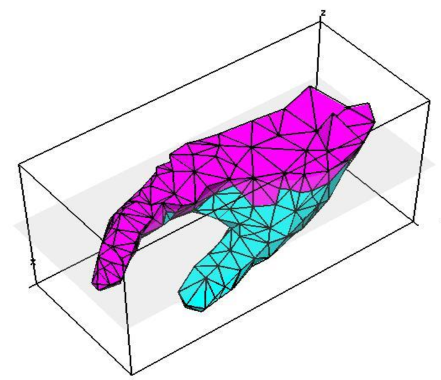

Fig. 3. Tetrahedralized hand model (red: cross sections)

Fig. 3. illustrates an image of a tetrahedralized hand polygon model cut in the z-axial plane using TetGen. For the red cross-sections, one may discover that the inner sides of the polygon are also filled with triangles. Each triangle is the cross section of each tetrahedron.

The TetGen command entered to perform the operation above was “pnAAYY.” Of the files obtained at this point, performing tetrahedralization of the smesh files from TetGen output will correct possible polygon errors.

However, simply defining targets of interest is not enough for completing MCNPX simulations. The geometry of the surroundings of a radiation source should be defined, as well as the medium between the radiation source and the target of interest. Consequently, the medium also should be tetrahedralized by placing the polygon model shown above inside a virtual box, including information on the medium according to the position of the radiation source. Generally, a medium can be defined as an uninterested domain on Boolean logic when defining a cell. However, for tetrahedralized model simulations, defining a medium on Boolean logic yields fatal errors when the number of words exceeds 2,000 in a single cell because there are too many sides.

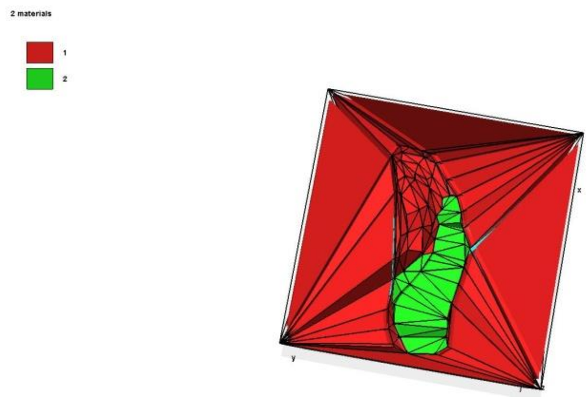

Fig. 4. A medium including the position of a virtual radiation source and the cut surfaces of the tetrahedralized model with respect to the target area of interest (red: medium; green: hand)

Fig. 4. shows a Tetrahedron model in which the medium was also tetrahedralized to avoid the aforementioned fatal errors. In doing so, a medium can be divided into a number of cells, and thereby fatal errors can be prevented. A medium can be added to the tetrahedralized model by drawing a sufficient number of boxes on the inputs of TetGen using a commercial 3D program. Once this is complete, TetGen performs tetrahedralization after segmenting areas, as shown in the figure above.

3. Creation of MCNP inputs

As the node and ele files produced by TetGen contain information on the construction of tetrahedrons resulting from the connection among coordinates, such files should be converted into MCNP input files which designate the inside of each side constituting tetrahedrons by creating a program in an appropriate way.

The program that should be created at this point consists of a part used for the calculation of a plane equation including three points, a part used for adjusting the direction of the plane for the central point of the tetrahedron to be positioned in a normal vector direction (due to the fact that a plane should be defined in MCNPX and the direction should be re-designated from cell cards), and a part used for removing overlapped sides. Here, the part used for removing overlapped sides represents the shared sides of each tetrahedron of the tetrahedralized model. The reason for doing this is not only to decrease computation time, but also to prevent the occurrence of “too many overlapped sides” fatal errors resulting from unremoved overlapped sides.

Table I. A process of converting tetrahedron model to MCNPX input

Fomat	Sort	Contents
PLY file	Output of 3D scanner Input of TetGen	X, Y, Z axial, Radical, Etc. (Polygon data)
SMESH file	Output of TetGen Input of TetGen	Node 1, Node 2, Node3 (A set of connected points = Polygon data)
↓	Running TetGen	
Node file	Output of TetGen	Node name, (X, Y, Z) axial (Points of tetrahedrons)
Ele file	Output of TetGen	Node 1, Node 2, Node3, Node4 (Connection information of nodes for tetrahedron)
↓	Computer Programming	
Surface card	MCNPX Input	4 surfaces from a tetrahedron in ele file Ex) Node1,2,3 and Node1,2,4 and Node1,3,4 and Node2,3,4
Cell card	MCNPX Input	Set surfaces vector toward the center of gravity of nodes Ex) (surface1 -surface2 surface3 -surface4): (surface5 -surface6 surface7 -surface8)…

Table I. shows summary of the surface card and the cell card creation process. In addition, the separation between a medium and the target area of interest should be performed using the material information stored in the ele file, and the aforementioned program should be loaded using this information.

III. RESULTS

1. The comparison between the tetrahedralized model and the voxel model

This study is largely divided into a part used for imitating target objects and a part used for MCNPX simulations. However, as the modeling figures above have shown that original shapes can be imitated to the maximum extent possible, making a comparison between the new technique and conventional techniques (the methods simplifying targets to a certain extent) is thought to be meaningless.

However, despite the fact that the MCNPX simulations after tetrahedralization were performed with the intention of using measurements unchanged and utilizing the benefits of polygon models, the tetrahedralized model and the voxelized model are going to be compared with each other, as there is an alternative capable of performing voxelization.

A randomly voxelized model was built for comparison purposes to check the results of dose estimations and simulation time of the tetrahedralized model. The slight differences between the shapes of the target of interest and the position of the radiation source result from the fact the voxelized phantom was created over the course of a process closely akin to drawing the tetrahedralized model.

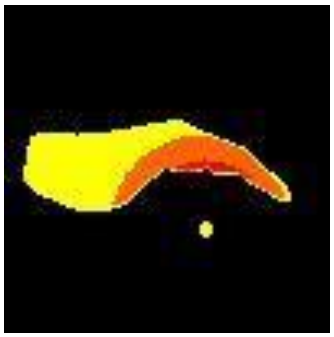

Fig. 5. Mesh tally of the tetrahedralized model (the vertical cross section of the center of a hand)

Fig. 6. Mesh tally of the comparison-purpose voxelized model (the vertical cross section of the center of a hand)

Fig. 5. and 6. are the mesh-tallied results of the Cs-137 dotted circles allocated in appropriate positions of the tetrahedralized model and the voxelized model. A customized tool was developed for drawing purposes and four different colors were applied according to the differences in doses. Though the voxelized phantom is somewhat different from the original object, the impact of changes in the positions of the dotted circles on the exposed areas can be clearly identified. On the contrary, as the dose affecting the specific distances of the dotted circles is constant, the dose estimation functions of both models are deemed identical.

However, the point closest to the radiation source in the tetrahedralized model was estimated to be a low dose. It is thought that the point might have been caused by an unsuitable mesh tally method for the tetrahedralized model. The geometry defined by the voxelized model is clearly consistent with that of the mesh tally. However, it seems that distortions occur on the outer sides of the tetrahedralized model as a result of the mesh tally interpreting the tetrahedralized model as a latticed structure even though the tetrahedralized model is not latticed.

The computation time of the two models on a 2.8 GHz hexa-core computer system was almost identical under the same mesh tally condition and 2e7 histories: for the tetrahedralized model, 729.67 minutes; for voxelized model, 720.11 minutes.

IV. CONCLUSIONS

This study proposed a method, which can imitate the geometry of a target object as closely as possible in a simplified way using a piece of 3D scanning equipment, is easy and accuate way to reflect motion characteristic and free curved surface. Furthermore, it can simulate polygon geometry in MCNPX without making any changes. However, the restrictions of MCNPX gave rise to some drawbacks, such as a decrease in the number of sides and the occurrence of distortions at the time of graphically interpreting doses. The drawbacks can be overcome and distortion-free dose information can be expressed and provided that the MCNPX source code is modified in such a way as to allow one to use a larger number of sides and to use the texture mapping of polygon models based on the ptrac information of MCNPX without using a mesh tally. A polygon phantom simulation takes time about 6-9 times compare to a voxel phantom in Geant.[9] But, A tetrahedron phantom takes similar time compare to voxel phantom in MCNPX.

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