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Research Paper

Mechanism of 3d Printing in Medicine and Dentistry

Dr.Bharani Krishna.T M.D.S[1],Dr.Ch.Ram Sunil M.D.S[2],Dr.Ch.Sujana
M.D.S[3],Dr.D.Loknathan Balaji M.D.S[4],Dr.Tejaswin. P M.D.S[5]
Corresponding Author: Dr.Bharani Krishna.T M.D.S
Senior Resident Department of Oral Medicine & Radiology
Drs.Sudha and Nageswara Rao Siddhartha institute of dental sciences

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The aim of a radiological exam is to examine the internal structure and morphology of an object while keeping it intact. By taking advantage of the matter's capacity to absorb X-radiation, knowing its initial (uniform) intensity. The absorption capacity of the matter depends on the physical properties of its basic parts (atoms). In medicine, the object is a patient, a three-dimensional structure, and the aim of a radiological exam is to diagnose any diseases; we can get real and accurate information only if we can reproduce the patient's characteristics in a three-dimensional image.

Suppose we light some three-dimensional bodies with a direct lamp according to a given direction, as in Figure below and that behind these bodies there is a wall on which their shadows are projected. As we can see, we get just little information about the bodies and we cannot know how many they are and how they stand or lay. Once again, the projection conceals the information along a dimension of space. Nevertheless, if we also examine the shadows that these bodies project on another wall, when lighted from another direction, we can have more information about them. In this example, we can see three bodies, the ones in the first shadow are cubes or cylinders with a round base; we can establish how they are arranged, etc. If we have two-dimensional information taken from two different directions, we can get a much more accurate three-dimensional description. We can intuitively understand that the more projections from different angles we have, the more accurate the 3D description will be. We now have to establish whether it is possible to get a 3D radiological characterization of a patient starting from 2D characterizations

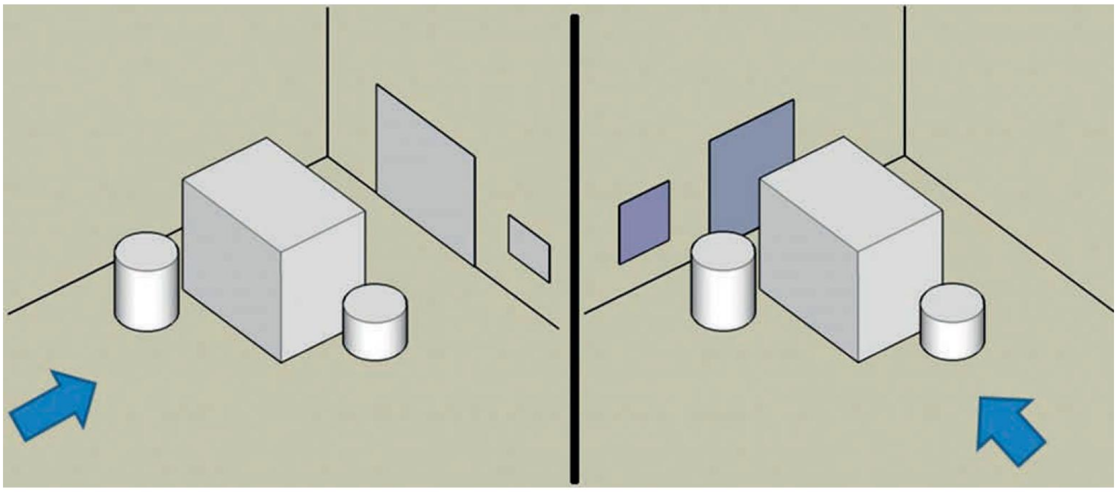


Fig. 2.11 Shadows of three-dimensional bodies projected on two walls.

We get a 3D radiological characterization of a patient after processing the data of his 2D characterizations (the traditional radiological images) obtained irradiating from different directions. The necessary processing capacity for reconstruction is only possible with digital information systems. This is why it would be convenient to start from digital two-dimensional radiological images (bitmaps). Since it is necessary to have several images obtained from precise and regular positions, it is clear that we must choose direct digital radiological systems because they have higher performances. After the calculating or reconstruction procedures, the information about the three-dimensional characterization will be inside the computer system and saved in a file. The user will have access to these data by means of a computer, in particular through a screen and a printer. How can this three-dimensional information (volume) be displayed on a screen or a printout that is two-dimensional,And how is it possible to access them? We shall discuss later. Now, we have to underline that the problem of how to use these data is at least as important as that of how to obtain them. The three-dimensional radiological information can be processed using software and computer programs which allow the user to navigate, extract, highlight, and modify these data properly. It is evident, then, that the 3D radiological activity is inherently a part of the digital world; outside of it, it cannot exist. Since the reconstruction, storage, and usage procedures and techniques are based upon software instruments, these will be essential for

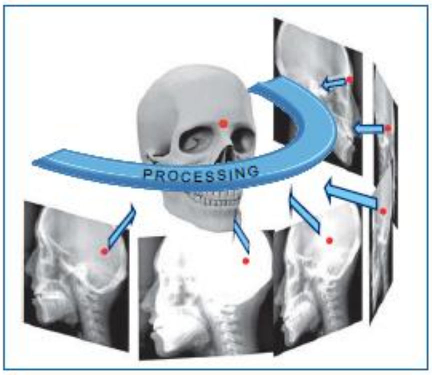
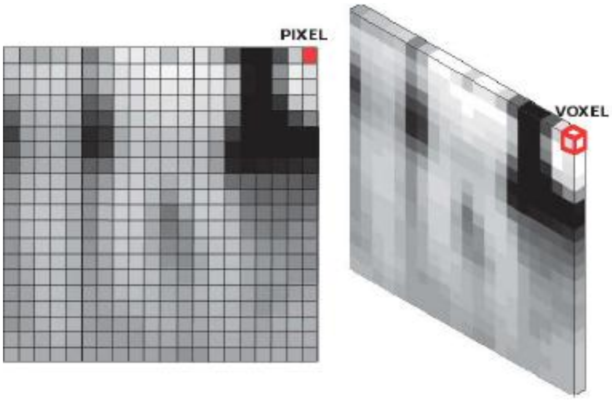


Fig. 2.12 Radiological reconstruction of 3D points from raw 2D data.

From pixel to voxel

The volume reconstruction performed by a digital system starts from raw data which are bitmaps, two-dimensional radiological characterizations obtained by means of two-dimensional grids of pixels, and leads to a three-dimensional grid made of voxels. The corresponding specific attenuation rate of each voxel will be calculated: similarly to what occurred with pixels, we will take that value of each voxel as homogeneous and constant in the entire volume enclosed. This is of course an approximation, according to which all the actual structures composing the real subject inside the volume enclosed by the voxel appear to be replaced by a homogenous substance as dense as their average value. As is the case with pixels in images, all the smaller details of the voxels fade in a uniform value and then are lost or incorrectly represented shown in figure below. It is easily understood that the information about a planar section of the grid (one-voxel thick) is the same as that of the bitmap obtained associating to each voxel one pixel with the same value (since the information along the thickness of one voxel does not change in the slice, no information will be lost). This idea is demonstrated clearly in figure below. It is evident that if the voxel is small enough to provide the necessary diagnosis, this is not a problem.



Voxels are called “isotropic” when their size is uniform in all three directions. With isotropic voxels, the space resolution of the available information is the same in all directions and there are no problems in object alignment which is a great advantage

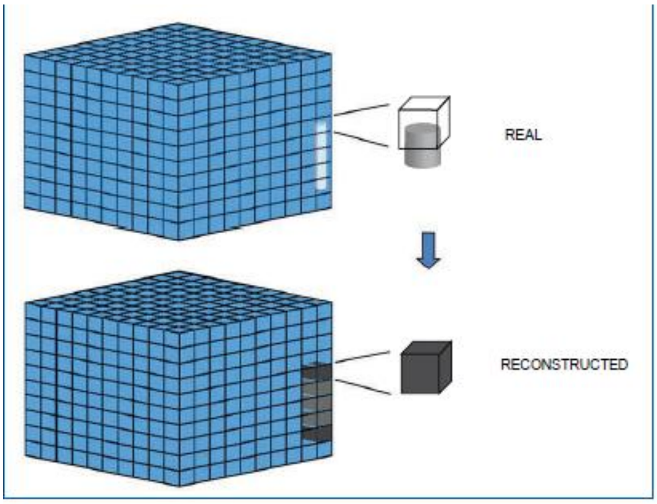


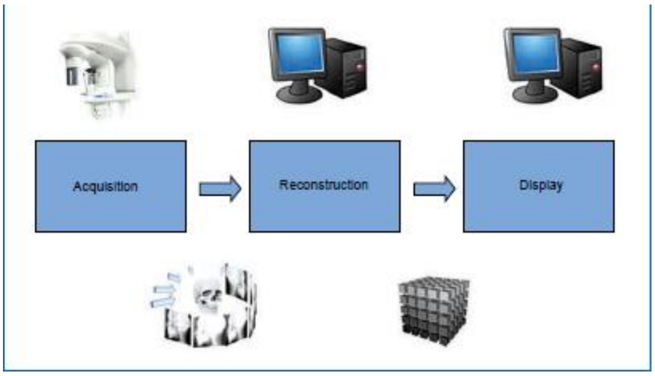
Fig. 2.14 Representation of a voxel matrix and detail of a voxel. Smaller real structures will get lost in the reconstruction process, which uses an average value of homogenous density for each voxel.

Data representation and storage

Storing on reliable and non-volatile supports (that is to say, supports which store information even when computers are off) is done by storing them in the form of a file, a collection of organized information. The specifications defining the structure and organization of files and of the information contained are usually referred to as the "file format". Any software will recover the information on files if it knows the file format—just as a foreigner will exchange information if he knows the language. If it is possible to determine a common language (a standard one), any file created in that language can be used by almost anyone. In medicine, they have developed a standard system of information and digital devices known as DICOM (Digital Imaging and Communications in Medicine). This was created and developed in the United States, and it has been used by other national and international authorities (in Europe, the Committee for Standardization has called it MEDICOM). This system is run by an international committee made up of experts and suppliers of medical items. It is updated to meet any new requirements and is frequently upgraded. For easy transfer and use of volumetric radiological data, DICOM is the universal format of the systems that are currently available; any clinician who has a DICOM reader can have access to data generated by any other system.

Work cycle and basic components of three-dimensional radiological systems

Every three-dimensional radiological system works following three main phases: acquisition, reconstruction, and display. These phases are strictly connected to three well-defined and usually separate parts.



ACQUISITION

The acquisition subsystem is definitely the most expensive part of the system, because it includes all the mechanical and electromechanical components that are necessary to run and position the X-radiation generator and the electronic receptor, the receptor and all electronic supply and control components. Furthermore, it should be equipped with the necessary electronic components to connect and exchange data with the other parts and with the outside world. Its task is to generate and supply the raw data from which the volume will be reconstructed. The features and quality of the acquisition system will determine the quality and availability of the information supplied by the 3D system. While working, the source will emit radiation, rotating together with the receptor, which captures the radiation portion left over after passing through the patient's body. He will be positioned with his body, or part of it, along the rotation axis. This axis together with a pair of other perpendicular axes will form the three main scanning directions of the system. They are the reference directions of the coordinates of the points of the volume scanned. In maxillofacial and dental applications, the patient's head is the scanning volume and the reference axes usually indicate the submentovertex (z-axis) direction, the forward-backward (y-axis) direction, and the condyle-condyle (x-axis) direction. While rotating, irradiation pulses are emitted from different angles. Detected by a sensor, they produce a series of conventional radiological data of the same object, but from different points of view—this is raw data. At present there are two available acquisition strategies that lead to two different systems: the so-called CT and CBCT.

Reconstruction

The reconstruction process is of key importance in establishing the quality of the resulting 3D data. This process includes all processing operations performed on raw data at the end of the acquisition phase. Its aim is to reconstruct the values to be associated to each voxel forming the digital volumetric radiological imaging of the object, algorithms, strategies, and numeric computation procedures used in this phase should be done following not only mathematical rules but also any steps to remove or reduce as much as possible any disturbances resulting from the real conditions (which are not the ideal ones because data are not complete or accurate, numbers are approximate, there is electronic noise, mechanical defects, sensitivity thresholds, etc.).

Display

The best-known visual device is the screen, on which the volumetric data will be displayed. How can we reproduce a three-dimensional image on a two-dimensional device like a screen? There are two possible solutions. The first solution is the easiest, and it consists of a drawing which uses the rules of perspective in order to achieve a realistic three-dimensional image. This is usually known as three dimensional "Rendering"As a matter of fact, the "rendering" technique is mainly useful for this, as it is not so effective in diagnosis. Parallel-section imaging should be chosen for diagnosis and all other clinical purposes. When we talked about the digital volume as a voxel matrix and we compared it with bitmaps, two-dimensional digital images, we underlined that any voxel matrix can be seen as a structure of several flat layers as thick as one voxel, each of which is actually equal to a bitmap. When we examine each layer, the three-dimensional data obtained are the same as if we "cut" our patient "into slices", so as to have a slice as thick as that layer, and we took a two-dimensional radiograph. It is obvious that this could be displayed on our screen. When any surface crosses a voxel matrix it will cover a given area. Even if it is curved, we can think about stretching it on a plane, translating the voxels concerned, exactly as we do with geographic maps. In this way, a group of voxels aligned according to a flat surface is obtained. They are equal to the bitmap of a two-dimensional image that we can produce on our screen. This operation of extracting the image of a direct section from the volume and according to a given flat surface is known as Multiplanar reformatting (MPR)

The two main systems of displaying data have been previously described, as well as their differences: rendering is useful for communicating with patients; cross-sectional MPR is preferable for diagnosis. Actually, MPR can also be useful for communication. Since it is more difficult, it should be used to examine further the aspects and information obtained with rendering. Rendering, too, can be used for diagnosis purposes as an auxiliary method in clinical and surgical planning

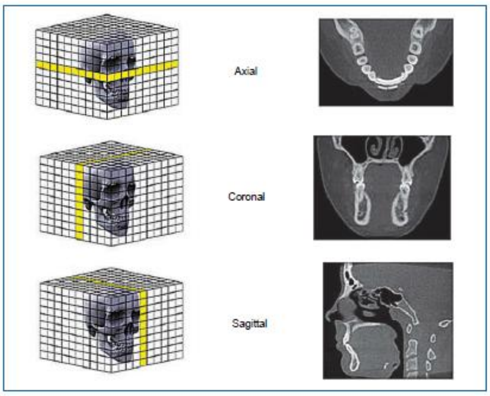


Fig. 2.21 Axial, coronal, and sagittal sections.

Dimensional "rendering". Rendering software is able to filter data and exclude voxels with given density levels, and it can hide or highlight only the structures to be examined and (virtually) alter the transparency level of overlapped data**.**

MULTIPLANAR REFORMATTING (MPR): General considerations and dental applications

When we first analyze volumetric radiological data by means of MPR sections, we are puzzled because we see images which are different from those of conventional two-dimensional radiology. First of all, we must understand where the section surface is oriented and what it looks like. We will then be sure that we are examining exactly what we want to and in a proper way. One of the most interesting advantages of MPR analysis of volumetric data with isotropic voxels (cubic voxels, with the same size in all directions of the Cartesian system) is to perform accurate linear and angle measurements of the anatomical structures in the sections extracted. All modern CBCT systems work with isotropic voxels and enable dentists to measure an implant location, the bone thickness, as well as the distance from the mandibular nerve, with no distortions and in full scale.

We will get accurate results provided that we use the correct evaluation section. In the case reported in Figure 2.22, the correct section is that where the bone thickness is the smallest, the one obtained in the plane perpendicular to the arch directory and tilted according to the direction of the main axis of the implant to be positioned, usually that along the directon on which the roots and crown of the original tooth develop. All MPR software is usually able to simultaneously display the axial, coronal, and sagittal sections passing through a point set by the user. This position may often be easily and interactively modified in real time, for a quick and orderly scrolling of volumes of adjacent sectionsin the directions perpendicular to the three sectionsIn dentistry, one of the most used MPR reconstructions is the panoramic one. The user chooses the most suitable axial section for his purpose. Then he identifies a curve on that plane, through points automatically joined together by the software. This curve usually covers the median area of the patient's arch or portion. The software will build a virtual surface perpendicular to the axial planes and as bent as the curve that identifies the group of intersecting voxels. If we develop this section on a plane, the transversal section too will be displayed perpendicular to the axial plane and the perpendicular projection. If we tilt this section with respect to the axial plane and keep it perpendicular to the arch, we will get the correct section to measure the smallest thickness of the bone and the distance as seen in the above example of the implant (Fig. 2.22).

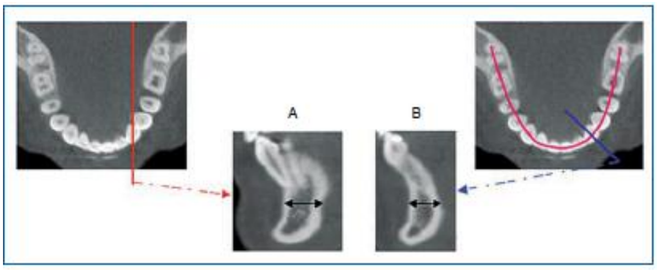


Fig. 2.22 Incorrect (A) and correct (B) selection of the transversal section to evaluate the bone thickness in an implant location.

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