Treatment planning ????o Modulation of the proton beam in range and intensity is accomplished by a rotating modulation wheel (also called "propeller"). o The wheel consists of varying thicknesses of plastic (e.g., polystyrene) with varying angular widths. o The thickness is constant in a given segment but successively increases from one segment to the other. o Whereas the water-equivalent range of the pristine peak is reduced by an amount equal to the water-equivalent thickness of the plastic in a segment, its intensity is reduced because of the increasing width of the segment (i.e., increasing beam-on time at that range position). o As the wheel rotates, the combination of pristine peaks with successively reduced range and intensity creates the desired SOBP (Fig. 27.10). Figure 27.10. Spread-out Bragg peak (SOBP) depth dose distribution, showing modulation width (distance between the distal and proximal 90% dose values) indicated by the vertical dashed lines. SOBP range is the depth of the distal 90% dose position. (From Kooy HM, Trofimov A, Engelsman M, et al. Treatment planning. In: Delaney TF, Kooy HM, eds. Protons and Charged Particle Radiotherapy. Philadelphia, PA: Lippincott Williams & Wilkins; 2008:70–107.) o A modern nozzle consists of many components for creating and monitoring a clinically useful beam (e.g., rotating range modulator wheel, range-shifter plates to bring the SOBP dose distribution to the desired location in the patient, scattering filters to spread and flatten the beam in the lateral dimensions, dose-monitoring ion chambers, and an assembly to mount patient-specific field aperture and range compensator). o These nozzle components are not standard and may vary between different accelerators. o The SOBP is specified by its modulation width, measured as the width between the distal and proximal 90% dose values relative to the maximum dose (indicated by vertical dashed lines in Fig. 27.10), and its range, measured at the distal 90% dose position. o SOBP beam parameters are generated by the treatment-planning system for each treatment field. o Lateral dimensions of the SOBP beam are shaped by a field aperture (corresponding to beam's-eye-view projection of the field to cover the target), typically constructed from brass with equivalent wall thickness exceeding the maximum possible SOBP range by 2 cm. o Thus, all the treatment beam parameters for each field, namely, beam energy, SOBP range and modulation, range compensator, field aperture, and dose, are designed by the treatment-planning system. C. DOSE CALCULATION ALGORITHMS o Several dose calculation algorithms for proton beam treatment planning have been developed. o Based on the basic formalisms used, they fall into three major categories: (a) PB, (b) convolution/superposition, and (c) Monte Carlo. o Some of these algorithms have been adopted by the commercial treatmentplanning systems (e.g., XiO by CMS, Inc., St. Louis, MO; Eclipse by Varian Medical Systems, Inc., Palo Alto, CA). oThe PB algorithm involves the calculation of dose distribution in infinitesimally narrow beams. o The given field is divided into a fine grid and the PBs are positioned on the grid along ray lines emanating from the virtual source position defining the beam geometry (Fig. 14.52). o Particles suffer energy degradation through inelastic collisions as well as lateral displacements through multiple elastic scattering, as discussed in Section 27.1B. o As a result of the elastic scattering interactions, the PB dose distribution gradually expands in lateral dimensions as it traverses the medium until the particles have lost all their kinetic energy through inelastic collisions. o The PB algorithm calculates the dose distribution in individual PBs, taking into account all the interactions and the medium heterogeneities. o The dose at any point in the patient is calculated by summing the dose contribution of

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all the pencils to the point of interest. o A number of PB algorithms (20–22) have been developed based on Moliere's theory of multiple scattering (23,24). o Moliere's theory involves a mathematic formalism for the angular distribution of proton fluence as a PB of high–energy protons penetrates a medium. o The angular distribution is described by a Gaussian function characteristic of multiple small–angle scattering (primarily by nuclei). o Terms for large–angle scattering and other corrections are also included. Hanson et al. (25) and Deasy (22) have used "best fit" functions to represent Moliere angular distribution by a single Gaussian term.Proton dose distributions can be optimized by the use of IMPT, achieving dose conformity comparable to IMRT but with much less integral dose.o These include acquisition of three–dimensional imaging data set, delineation of target volumes and organs at risk, setting up of one or more beams, selection of beam angles and energies, design of field apertures, optimization of treatment parameters through iterative or inverse planning, display of isodose distributions and dose volume histograms (DVHs), and so on, depending on the complexity of a given case.o Also, corrective techniques, such as "smearing" the range compensator, may be used to counteract the effects of some of the uncertainties (18,19). o The smearing procedure consists of adjusting the compensator dimensions within the smearing distance, based on the geometric and target motion uncertainties, and thereby shifting its range profile to ensure target volume coverage during treatment (even at the expense of target volume conformality). o The need and complexity of this procedure require that the proton beam treatment–planning systems must incorporate a smearing algorithm and provide details for the fabrication of the "smeared" range compensator.4.3 Illustrations of (a) passive scattering and (b) pencil beam scanning delivery systems o uses conversion schemes such as the stoichiometric CT calibration method, where CT scans of materials of known elemental composition and density are used to generate a conversion table for HU to proton stopping power(4).The accuracy of localizing the distal dose gradient is marred by several uncertainties: subjective element in target delineation, variations in patient setup, patient and internal organ movements during treatment, and accuracy limitations of the dose calculation algorithms.oThe planning system output for the selected plan includes the necessary treatment parameters to implement the plan (e.g., beam coordinates, angles, energies, patient setup parameters, isodose curves, DVHs, and digitally reconstructed radiographs).o Because of the very sharp dose drop–off at the end of the beam range and laterally at the field edges and uncertainties in the computed tomography– based water–equivalent depths, calculated beam ranges, patient setup, target localization, and target motion assume greater importance for protons than for photons.D. CLINICAL APPLICATIONS Proton beam therapy has been used to treat almost all tumors that are traditionally treated with x–rays and electrons (e.g., tumors of the brain, spine, head and neck, breast, and lung; gastrointestinal malignancies; and prostate and gynecologic cancers).o While other imaging modalities (e.g. magnetic resonance imaging (MRI), positron emission tomography (PET)) may be used to aid identification of the target volume, the treatment planning process and dose calculations are performed using the X–ray CT image alone.o Patients are then imaged in the treatment position on a computed tomography (CT) scanner using kilovoltage X–rays, and outlining of the target volume(s) and relevant .(organs–at–risk (OARs) is performed on this image.Fig.??????????27.10

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