Failure of local tumor control is still a problem in about 20% of all cancer patients. Due to this fact, there is an urgent need for the optimization of existing and development of new and more effective treatment techniques for localized tumors. Research at the division of Medical Physics is focused on new conformal radiotherapy techniques with photons, electrons and hadrons. Major achievements of the last two decades were the introduction of 3D treatment planning, Stereotactic Radiosurgery, 3D Conformal Precision Radiotherapy, inverse treatment planning, Intensity Modulated Radiotherapy and Radiotherapy with Carbon-12 Ions.

Besides the ongoing projects in Hadron-therapy, our future work will be concentrated on establishing mathematical and biological models of tumour and normal tissue response and on the consideration of dynamic changes of target volumes (PTVs) and organs at risk (OARs) under therapy, either caused by therapeutic response, by organ movements or by patient repositioning. The approach we are going to develop is called Adaptive Cone Beam Therapy. It will combine conformal dose delivery with online imaging of 3D anatomy and on-line monitoring of 3D dose distributions.

Based on the experience and technology from radiotherapy developments, we are also going to develop and investigate new methods in Neurosurgery, especially using short pulsed lasers and photo dynamic therapy (PDT).

The skills of the division cover Computer science, Medical Radiation Physics, Mathematics, as well as Mechanical and Electronic Engineering. It is one of the major advantage of our division that prototypes of software and hardware developments can directly be transferred within the same building into clinical application in close connection and cooperation with the Clinical Cooperation Unit Oncological Radiotherapy (J.Debus). Thus the division is also active in testing and evaluating the new techniques as well as in establishing adequate QA programs.
Physical Models (E0401)


In collaboration with: Dr. K.-H. Grosser, Dr. R. Bendl, A. Höss, Prof. G. Hartmann, Dr. O. Jäkel, DKFZ, Abt. Medizinische Physik; PD Dr. Dr. J. Debus, DKFZ, Klinische Kooperationseinheit Strahlentherapeutische Onkologie; B. Rhein, P. Haring, DKFZ, Zentraler Strahlenschutz / Dosimetrie; Dr. C. Schulze, Dr. J. Stein, MRC Systems, Heidelberg; Prof. S. Webb, Dr. P. Evans, Royal Marsden Hospital, Sutton, UK; J. Hughes, Siemens Oncology Care Systems (OCS), Concord, USA; Dr. A. Lomax, Paul Scherrer Institute (PSI), Villigen, Switzerland; Dr. B. Mijnheer, The Netherlands Cancer Institute (NKI), Radiotherapy Department, Amsterdam, The Netherlands Cancer; Prof. H. Kooy, Massachusetts General Hospital, Dept. of Radiation Oncology, Boston, USA; Prof. F. Nüsslin, M. Alber, Universität Tübingen, Institut für Medizinische Physik; Dr. D. Jaffray, Department of Radiation Oncology, William Beaumont Hospital, Royal Oak, MI USA; Prof. M. Kröning, Dr. M. Maiel, Fraunhofer Institut für Zerstörungsfreie Prüfverfahren (IZFP), Saarbrücken; Prof. A. K. Louis, Institut für Angewandte Mathematik, Universität des Saarlandes, Saarbrücken; Prof. H. W. Hamacher, PD Dr. K.-H. Küfer, Institut für Techno- und Wirtschaftsmathematik, Kaiserslautern; Prof. R. Männner, PD Dr. J. Hess, Universität Mannheim, Lehrstuhl für Informatik V

Our objective is the improvement of tumor therapy through the development and application of mathematical and physical models. We focus on the optimization of radiotherapy, particularly on so-called intensity-modulated radiotherapy (IMRT) [1,6,12]. Building upon our efforts in the last few years it has been possible to treat more than 140 patients at DKFZ and at the Radiological University Clinics with IMRT based on our planning system KonRad. Thereby the patients could be treated with higher doses in the tumor target volume and/or with better sparing of the surrounding normal tissues. Worldwide over 1000 patients have been successfully treated with IMRT on the basis of our optimization programs.

In one project of our working group we investigate the application of the IMRT concept to irradiation with charged particles, in particular with protons [5,15] (IMPT, intensity-modulated proton therapy) and with heavier ions. The methods of inverse therapy planning for photons have been transferred to charged particles and have been extended by one dimension in order to optimize not only the intensities but also the energies of the used particles [9,10]. Parallel to the theoretical investigations of new irradiation techniques with charged particles (e.g. “Distal Edge Tracking”) for simple model cases, we have developed and implemented a new modular planning platform for the IMPT. At present the new multi-modality components of the KonRad program are being evaluated (in particular the optimization module and the dose calculation). This covers separate tests of the optimization and the dose calculation using photons, as well as planning studies for typical clinical cases using various irradiation techniques. The application of the new IMPT planning procedures and further developments, e.g. regarding biological characteristics of charged particles, are examined in co-operation with the leading centers in the field of particle therapy (NTPC Boston, PSI Villigen (Switzerland) and GSI Darmstadt).

Fig. 1: Comparison of a photon IMRT dose distribution (a) with a proton IMPT distribution (b) for a prostate case. IMRT allows to achieve good conformation of the high-dose region to the tumor target volume (red line), but a significant amount of normal tissue is treated with medium dose values (yellow and green areas). IMPT yields an excellent conformal dose distribution at all dose levels.

The development of a multi-criterion optimization concept for radiotherapy is planned. The probability of local control and possible complications are evaluated separately and optimized for individual radiation-sensitive “organs-at-risk”. First estimates suggest that, by taking this approach, better results can be obtained than with past optimization procedures, in which the entire irradiation plan was evaluated simultaneously.

Another important aspect of our work is Monte Carlo simulation for radiation therapy. This comprises on the one hand the problem of dose calculation in patients in complex irradiation situations [13]. On the other hand, Monte Carlo is used for the simulation of treatment machines and equipment [8]. For this purpose the GEANT program from CERN has been implemented.

Equally important as achieving a highly conformal dose to the tumor is the verification side of therapy, since small changes in the region of interest might have an impact on tumor control and normal tissue complication probabilities. Our investigations have shown that anatomical sectional views of the patient produced with the therapy beam (MVCT) can contain all the necessary information for a complete verification. For these investigations we use amorphous silicon (a:Si) flat panel detectors. The verification process consists of two parts: CT imaging and the dose reconstruction (transit dosimetry) based on these CT images. Problems arising from mechanical instabilities of the detector attached to the rotating linac gantry have been solved using an off-line correction [16]. A further problem in transit dosimetry is scattered radiation produced as the beam traverses the patient, which overlays and degrades the image. By means of Monte Carlo calculations we have shown that scattered photons, which are mainly in the low energy region, can give rise to a disproportionately large signal in a:Si flat panel detectors [11,14,17,18]. Studies have been carried out to optimise the composition of the converter plate (metal/scintillator) such that the detector becomes less sensitive to these low energies.

A further aspect of our imaging research has been the development and implementation of a 3D algorithm for image reconstruction [2,3] using cone beam geometry. Thus the distribution of the electron density over the entire treated
volume can be reconstructed with only one rotation of the gantry. At present it is being investigated whether reconstructions are also possible from a reduced range of gantry angles allowing for faster examinations with a smaller dose to the patient. In collaboration with the University of Mannheim a prototype of a dedicated reconstruction hardware is designed to achieve online 3D reconstruction. The objective of this online imaging technique is to detect errors in the positioning of the patient and organ movements. Such knowledge of organ motion and positioning errors are also currently being studied and the expected dosimetric effects quantified. This work forms the basis of a plan to include these errors in the optimization process and to produce strategies for adaptive radiotherapy.

In an industrial collaboration the efficiency of each single step of the IMRT procedure was investigated to make a transfer of the IMRT technique into the clinical practice of many hospitals possible [4]. To achieve this goal a data base was set up to investigate the possible use of class solutions for specific clinical situations. Furthermore, the time effort for therapy planning, verification and documentation was reduced by improving existing techniques as well as implementing new devices and tools. As a last step, workshops and site visits were held to train physicists, physicists and technicians in the IMRT method. Grants: Tumorzentrum Heidelberg/Mannheim: 1 position (BAT IIb); Industrial collaboration Siemens: 1 position (BAT IIa); Strategiefonds Helmholtzgemeinschaft: 2 Post-Doc positions (BAT IIa); DFG: 1 position (BAT IIa), 2 Ph.D. positions

Selected Publications (* = external co-author)


Biological Models (E0402)

S. Levegrün, K. Borkenstein, A. Mahr, Lan Ton

In cooperation with: PD Dr. J. Debus, Dr. P. Peschke, Klinische Kooperationseinheit Strahlentherapeutische Onkologie, FS Radiologische Diagnostik und Therapie, DKFZ; Dr. A. Jackson, Dr. C. C. Ling, Department of Medical Physics, Memorial Sloan-Kettering Cancer Center, New York, USA; Dr. M. J. Zelefsky, Dr. Z. Fuks, Dr. S. Leibel, Department of Radiation Oncology, Memorial Sloan-Kettering Cancer Center, New York, USA; Dr. M. L. Bahner, Abteilung Onkologische Diagnostik und Therapie, FS Radiologische Diagnostik und Therapie, DKFZ

The aim of any tumor therapy with curative intent consists in the eradication of the tumor without causing severe side effects. In radiation therapy, the dose required to achieve local tumor control is often compromised by the increasing risk of complications in surrounding critical organs and healthy tissues. To optimize radiation therapy, the treat- ment plan leading to the best compromise between high tumor control probability and low risks of adverse effects must be found for each individual patient. In the process of radiotherapy treatment planning, radiation oncologists have to assess the likely biological effect of a planned physical dose distribution, which is a complex task. At present, treatment decisions are entirely based on clinical experience of tolerance doses in various normal tissues and empirical knowledge of volume effects (i.e. the observation that in many organs complication probabilities in- crease when increasing fractional volumes of the organs are irradiated). Therefore, efforts are being made to de- velop new tools to quantitatively evaluate treatment plans. To quantify the biological effect of a delivered dose distri-
bution, biological models have been proposed that attempt to describe the response of tumors and normal tissues to irradiation. The ultimate goal of these models is to reliably predict tumor control probability (TCP) and normal tissue complication probabilities (NTCP), based on the physical dose distribution and radiobiological parameters. The projects of the working group focus on the investigation of volume effects, the quantification of dose-response relations and the evaluation of current biological models as tools for treatment planning.

The aim of one investigation of the working group was to evaluate the usefulness of existing models to predict normal tissue complication probabilities after radiosurgery of patients with cerebral arteriovenous malformations (AVM). The study concentrated on radiation-induced tissue changes on follow-up neuroimaging (e.g. edema, blood-brain-barrier breakdown, necrosis). Outcomes for 286 AVM patients who received stereotactic Linac radiosurgery at DKFZ were retrospectively analyzed and compared to the predictions of existing models [1-3]. In addition, dose-response relations were investigated. The comparisons indicated that risk prediction models may allow the identification of patients with a high probability of adverse effects. However, further evaluations of the merit of current models as tools to guide treatment planning for lesions in the brain are required.

In cooperation with the Departments of Medical Physics and Radiation Oncology at Memorial Sloan-Kettering Cancer Center (MSKCC), New York, late radiation effects in the rectum [4-6] and local tumor control [7,8] after three-dimensional conformal radiation therapy of prostate cancer patients were retrospectively analyzed. Since December 1988, more than 1200 patients with stage T1c-T3 clinically localized adenocarcinoma of the prostate were enrolled in a phase I dose-escalation trial at MSKCC. Patients were treated with conventional photon beam 3D-CRT and intensity-modulated treatment techniques to prescribed doses between 64.8 and 86 Gy. To assess local tumor control, a subset of the patients underwent a post-treatment prostate biopsy at least 2.5 years after end of radiation therapy. Variables derived from the dose distribution of individual patients and tumor-related prognostic factors that correlated with biopsy outcome were identified. The usefulness of several existing TCP models as predictors of biopsy outcome was evaluated and a multivariate model to predict biopsy outcome was derived. The results may help to identify patients, based on their individual pre-treatment prognostic factors, that would benefit most from dose-escalation and to guide dose prescription.

In 1999, the working group started a new project, the modeling and computer simulation of tumor growth and of tumor response to various treatment modalities [9]. The goal of the project is to integrate simulated tumor control probabilities into the treatment planning process to assist radiation oncologists in their decision making. Creating realistic models requires a thorough understanding of the biology of tumor cell growth and tumor response to different treatments such as radiation therapy. For this reason, the modeling is done in close cooperation with the Radiobiology Group of the Division of Radiation Oncology (Klinische Kooperationseinheit Strahlentherapeutische Onkologie) at DKFZ. The developed model takes into account individual tumor cells. This allows to include a variety of cell biological parameters. Tumor growth is modeled using basic mechanisms for cell growth and death: Cell cycle phases and their duration, control mechanisms for inactive cells and apoptosis, oxygen supply and resorption of necrotic and apoptotic cells. At the beginning of tumor growth the microvasculature is modeled via a homogeneous capillary distribution. Hypoxic areas in a tumor’s interior will induce angiogenesis. Modeling of tumor response to radiation therapy is based on the linear-quadratic model. The radiosensitivity of each cell depends on its oxygen supply and its cell cycle phase. Complete repair is assumed between fractions. Computer simulation is performed on a 3D rigid cubic lattice. Growth is initiated by a single tumor cell dividing after one cell cycle time $T_C$. Random processes such as cell displacement after cell division and DNA-damage are simulated by Monte-Carlo techniques. The $T_C$’s and sensitivities of the cells are normally distributed. Tumor growth and tumor response to radiation can be simulated for macroscopic tumors with a size of up to 12 mm (see Figures 1 and 2).

Another area of research has been the development and evaluation of a computer system to determine tumor volumes within clinically required accuracy as a tool to support therapy decisions, therapy monitoring and the assessment of tumor response to treatment [10,11]. In a detailed study, different available volumetry systems based on semiautomatic image segmentation algorithms were compared. The best algorithm was re-implemented into a new volumetry system. The delineated data are then analyzed and compared to values in a local knowledge-base. This knowledge-base consists of data gathered from extensive phantom studies. Depending on the size and contrast of the tumor, an uncertainty factor is deduced from the knowledge-base. This factor is combined with a user-dependent uncertainty factor derived through regular delineations of test data by every user. The combination of these two factors allows to assess the accuracy of the delineation. Hence, the new system will not only provide absolute volume information but also detailed information about the reliability of the result. Eventually, this system will lead to a higher clinical acceptance of volumetric information and provide the basis for the clinical implementation of tumor volumetry to monitor tumor response to therapy and to individualize treatments.

Publications (* = external co-author)


Fig 1: Planes through a spherical tumor with 25 Mio. cells before radiation. T$_{c}$=2d. There are necrotic centers in the tumor’s interior (black), some of which have already been resorbed (white). This tumor model does not include angiogenesis.


Fig 2: Planes through the tumor of Fig. 1 after 2 weeks of radiation with 10 fractions of 2 Gy each. Most necrotic and apoptotic cells have been resorbed.


Therapy Planning – Development (E0403)

R. Bendl, J. Dams, B. Dobler, M. Kieber, A. Lüttgau, M.A. Keller-Reichenbecher, K. Pfeiffer

In cooperation with: PD Dr. J. Debus, G. Hartmann, A. Höss, O. Jäkel, A. Lorenz, I. Zuna, DKFZ; Dr. M. van Kampen, Dr. G. Stoka-Pérez, Radiologische Universitätsklinik Heidelberg; Dr. Bonsanto, Dr. A. Staubert, Neurochirurgische Universitätsklinik Heidelberg; Dr. K. Welker, Dr. K. Zink, M. Scholz, Klinikum Moabit, Berlin; Prof. Dr. V. Sturm, Dr. R. Lehrke, Dr. K. Luyken, Dr. H. Treuer, Klinik für stereotaktische und funktionelle Neurochirurgie, Universität Köln; Prof. Dr. J. F. Bille, Institut für Angewandte Physik, Universität Heidelberg; Dr. M. Götz, Dr. S. Fischer, MRC Systems, Heidelberg; Dr. H. Fuchs, Dr. H. Kluge, Dr. C. Reithfeld, Hahn-Meitner-Institut, Berlin; Dr. Nausner, Dr. Bechakis, Universitätsklinikum Benjamin-Franklin, Berlin

The task of the group „Therapy Planning - Development“ is the investigation, development and implementation of computer assisted tools, which can improve the planning, simulation and evaluation of minimal-invasive treatment techniques in oncology. In this way, clinicians should be enabled to plan, test and optimise their treatment strategies pre-therapeutically.

There is no doubt, that a pre-therapeutical treatment optimisation can increase the overall treatment results: better local tumour control, less side effects and a reduction of treatment time in surgical interventions, faster recovery of the patient and consequently a reduction of treatment costs. Due to the close cooperation of physicians, physicists and computer scientists our institute is the ideal environment for developing computer assisted planning and simulation methods with clinical relevance. One superior intention of all developments is a careful elaboration of promising methods in a way, that their ben-
benefits can be demonstrated directly in real patient treatment. The former activities were focused on methods for three-dimensional conformal radiotherapy planning. Because there are a lot of similarities in computer assisted tools for planning and optimising other minimal-invasive treatment techniques, we try to extend the available experiences and to generalise new developments in a way that other therapeutic approaches may derive benefits, too.

The working areas of the group include all links of the therapeutic chain that can be supported by computer assisted tools. Special emphasis is put on image processing, registration of multi-modal image sequences, segmentation, three-dimensional modelling, representation and visual presentation of anatomy, visual simulation of treatment approaches and virtual reality, presentation of numerical simulation results and appropriate evaluation tools, knowledge based systems for therapy planning and methods and tools for therapy monitoring. We have concentrated our activities on the following topics:

1. Registration of multi-modal images, segmentation and representation of anatomical structures
2. Knowledge based radiotherapy planning
3. Stereotactic laser neurosurgery
4. Planning system for the proton therapy of eye tumours
5. VIRTUOS, VIRTUal RadiOtherapy Simulator
6. New technologies for transferring therapeutic knowledge

The main strategy can be divided into two sub-goals. The first one is the continuous further development of the existing radiotherapy planning software as a support to the Clinical Cooperation Unit „Radiation Oncology” (PD Dr. Debus, E0500), to enable this group to continue and extend their scientific work. They need a reliable state of the art planning system, to which new functionalities can easily be added. In addition to activities 1, 2 and 5 the further development of the system for its use in the “Heavy Ions Therapy Project” (Dr. Jäkel. GSI/DA-Project E0409)[2] is one of the important tasks.

In activity 2 we have investigated a new approach which will not only speed up the generation of three-dimensional treatment plans markedly, but will allow the systematic collection of well proven treatment strategies [3]. Together with Dr. Welker, Klinikum Berlin-Moabit, radiotherapeutical treatment strategies have been collected and will be integrated into the knowledge based system in future. This way the system will allow a continuous exchange of therapeutic knowledge between different research and therapy centres. In activity 6 we develop methods and strategies which should permit easy distribution of approved treatment strategies via an internet-based information system.

Besides the development of new methods a central objective of our efforts is to enable other clinicians to use 3D therapy planning for routine patient treatment and to spread out planning tools and promising therapy strategies. Therefore, commercial cooperations are used to distribute the developed planning tools to other clinics and research centres. In one cooperation our VIRTUOS program was made ready for the market and is now distributed by STRYKER-Leibinger, Freiburg.

The second sub-goal is the extension and adaptation of the developed planning strategies and tools to new minimal-invasive therapy concepts. On one side this means a generalization of planning concepts. On the other side these activities should result in dedicated planning systems, which should enable clinicians to plan, simulate, optimize and evaluate interventions pre-therapeutically.

In activity 4 we develop together with Dr. H. Fuchs and Dr. H. Kluge, Hahn-Meitner-Institut Berlin a planning system for therapy of eye tumours with protons (Fig.: 1). Proton therapy of eye tumours has shown good clinical results (96% local tumour control). It is carried out in some specialised institutes all around the world. At HMI Berlin the first therapy facility for that kind of treatment in Germany was established in 1998. For planning therapy normally the program EYEPLAN is used (developed by M. Goitein in the early eighties). Since three-dimensional image modalities were not widely used at that time, planning and dose calculation is based on a simple spherical model of the eye. This results in uncertainties, which must be compensated by relatively large security margins. If the distance of tumour and sensitive structures (optical nerve, macula) is smaller than 3 mm, conventional treatments can lead to a loss of functionality of that structures. The aim of the project is therefore, to establish a precise model of the eye (by using modern image modalities, CT, MRI and fundus photographs) and this way the precision of therapy should be increased, to reduce possible side effects (loss of sight). At DKFZ we have developed a real-time dose calculation algorithm, which presents the expected dose distribution synchronously to adjustments of the irradiation direction [4]. This way planning time should be reduced noticeable. To increase the precision of pre-calculated dose distributions an additional pencil beam algorithm will be integrated by the partners in Berlin.

Fig. 1: Mapping of a fundus photograph on the three-dimensional model of the eye, which was established based on a sequence of CT images. Visible structures: Cornea, Lens Optical Nerve, Tumour and Clips, which were sewn on the sclera for controlling the treatment position
An additional promising approach is investigated in activity 3 (stereotactic laser neurosurgery) together with Prof. Bille, Institute for Applied Physics, University Heidelberg and Prof. Sturm Clinic für stereotactische Neurosurgery, University Cologne and MRC Systems Heidelberg. By means of an ultra short pulsed laser deep-seated brain tumours should be resected without diffuse thermal damage of the surrounding tissue [1]. The application of such interventions will depend on the availability of suitable planning and monitoring tools. Therefore we develop a dedicated planning system for that new kind of therapy. Meanwhile a first prototype was installed at the clinical cooperation partners. In collaboration with the future users that prototype was evaluated and is now adjusted to the clinical needs. To monitor the application of the short-pulsed laser different intra-operative imaging modalities were investigated [5]. Since interventional MR scanners are not widely used up to now, we have investigated how 3D ultrasound can be used as intra-operative imaging modality [5]. The development of intra-operative monitoring facilities will have important influence on other surgical treatment concepts, too.

Nearly all activities of the group were financed substantially by the DFG (german research community) the Deutsche Krebshilfe and fundings supplied by industrial cooperation partners.

Publications (* = external co-author)


**Therapy Planning - Application** (E0404)

A. Höss

In cooperation with: Prof. Dr. N. Ayache, INRIA, Sophia Antipolis, France; Prof. Dr. M. Bamberg, Dept. for Radiotherapy, University of Tübingen; Dr. M.L. Bahner, Div. of Oncological Diagnostics and Therapy, DKFZ; Prof. Dr. H. Blattmann, Paul Scherrer Institute, Villigen, Switzerland; Dr. J. Bohsung, Dept. of Radiotherapy, Charité, Berlin; PD Dr. T. Borfeld, Prof. Dr. R. Bendl, Prof. Dr. G. Hartmann, Div. of Medical Physics, DKFZ; PD Dr. Dr. J. Debuc et al., Clinical Cooperation Unit Radiation Oncology, DKFZ, Prof. Dr. R. Felix, PD Dr. P. Wust, Virochow-Klinikum, Berlin; Dr. D.T.L. Jones, Dr. A.N. Schreuder, National Accelerator Centre, Faure, South Africa; Prof. Dr. G. Kraft, Gesellschaft für Schwerionenforschung mbH, Darmstadt; MRC Systems GmbH, Heidelberg; Prof. Dr. G. Nemeth, Dr. O. Esik, National Institute of Oncology, Budapest, Hungary; Nucletron B.V., Veenendaal, The Netherlands; Prof. Dr. F. Nüsslin, Dept. of Medical Physics, University of Tübingen; B. Rhein, P. Häring, Prof. Dr. L. Schad, Dept. of Biophysics and Medical Radiation Physics, DKFZ; Prof. Dr. J. Richter, Clinics for Radiation Therapy, University of Würzburg; Dr. S. Scheibl, Klinik Im Park, Zurich, Switzerland; Prof. Dr. R. Schmidt, Dept. of Radiotherapy, University Hospital Eppendorf, Hamburg; Dr. U. Schneider, Clinics for Radiooncology and Nuclear Medicine, Zurich, Switzerland; Stryker Leibinger GmbH, Freiburg; Prof. Dr. V. Sturm, Dept. for Stereotact & Functional Neurosurgery, University of Cologne; Prof. Dr. M. Wannenmacher, Radiologic University Hospital, Heidelberg; Prof. Dr. S. Webb, Dr. J. Bedford, Royal Marsden Hospital, Sutton, UK

The task of the working group is the integration, pre-clinical testing, support, maintenance and quality assurance of software modules and packages designed for 3D treatment planning which have been developed by members of the Division of Medical Physics and are afterwards put at the disposal of the Clinical Cooperation Unit Radiation Oncology (E0500) for clinical testing. The VOXELPLAN project, initially funded by the Deutsche Krebshilfe, has demonstrated impressively the scientific and clinical potential of the software packages developed by the Division of Medical Physics. The unique research environment given in the Research Program Radiological Diagnostics and Therapy enables an interdisciplinary close cooperation of physicians, physicists and computer scientists resulting in a direct benefit to thousands of cancer patients treated with 3D conformal radiotherapy and intensity modulated radiotherapy in clinical trials at DKFZ [1-6,8] and at the sites of its cooperation partners [7,9]. In addition to this major clinical activity the software packages supported by the group serve as carrier systems for research activities of members of the Division of Medical Physics as well as of their national and international scientific cooperation partners.

Until recently, there have been few regulations in Europe concerning medical equipment, and there still is a lot of uncertainty on behalf of „manufacturers“ of „medical devices“ like DKFZ, if and how to employ the new Medizinproduktegesetz and its ordinances derived from the European Medical Devices Directive (93/42/EWG). As the medical devices built by the Division of Medical Physics are not „placed on the market“, but only „put into service“ within the Clinical Cooperation Unit Radiation Oncology they do not need to bear the CE mark indicating that they have been subjected to a conformity assessment procedure. However, the obligation remains to keep the risk to the patient justifiable compared with the potential benefit, and to carry out quality assurance procedures complying to state-of-the-art safety standards and applicable law. As there is also an obligation to notify the authorities about the manufacturing, servicing or marketing of medical devices - and to report any incidences - the competent authorities were contacted and a preliminary certificate of exemption for the further clinical application of radiotherapy equipment manufactured in-house was obtained. Due to ongoing efforts by the legislator to facilitate compliance with the new regulations by enacting and modifying specific laws and ordinances, the working group is following up the state of affairs and fulfilling the associated qualifications (e.g. compilation of medical devices books).
During the period under report a completely revised, UNIX based version of VOXELPLAN was implemented, tested and finally released for clinical evaluation - in conjunction with the IMRT software package KonRad - in close cooperation with the working groups “Therapy Planning – Development (E0403), “Physical Models (E0401)” and “Biophysics and Radiotherapy Physics (E0408).” This new version compensates any known shortcomings of its predecessors and contains a wide range of new features and functionalities to simplify and speed up treatment planning procedures and to facilitate the introduction and evaluation of new irradiation techniques. Supplemental quality assurance tools have been implemented to check the correctness and reliability of the planning systems as well as the consistency and integrity of the patient data and devices parameters which are all decisive for the quality of the resulting treatment plans. These tools can be employed to monitor the quality of such systems, and to direct quality assurance activities. However, although the development and application of dedicated treatment planning software is a major clinical activity of the Division of Medical Physics, the efforts to shift routine work to commercially available systems were further intensified due to the additional expenses - in terms of manpower and other resources - caused by the obligation to comply with regulations during the permanent operation of non-CE certified systems, and especially when newly developed software is put into service. The objective is to ensure the availability of the in-house systems for research purposes – provided that the resources remain constant - by discharging them from as many routine tasks as possible. The working group therefore also covers the commissioning, operation, servicing and quality assurance of the CE certified treatment planning systems available at DKFZ.

Publications (* = external co-author)


Hardware Developments and Technical Systems (E0405/E0406)


In cooperation with: Howmedica Leibinger GmbH, Freiburg; Dr. A. Hamilton, University of Arizona Health Sciences Center, Tucson, USA; Priv. Doz.. Dr. Dr. J. Debus, Clinical Cooperation Unit Radiation Oncology, DKFZ; Dr. K.-H. Höver, Prof. Dr. Dr. W.Semmler, Div. of Biophysics and Medical Radiation Physics, DKFZ; MRC Systems GmbH, Heidelberg, Prof. Dr. J. Richter, Clinics for Radiation Therapy, University of Würzburg; Prof. Dr. V. Sturm, Dept. for Stereotactic & Functional Neurosurgery, University of Cologne; Prof. Dr. Dr. M. Wannenmacher, Radiologic University Hospital, Heidelberg; Zett Mess Technik GmbH St. Augustin; Siemens Medical Systems, Inc. Oncology Care Systems Group, Concord, USA.

The aim of radiation therapy is to eradicate a tumor without causing significant damage to contiguous normal tissue, especially to organs at risk. These demands define the guidelines for two important concepts in radiotherapy: Spatial conformation of the radiation dose to the target and fractionation of the treatment.

Spatial conformation of the dose to the target allows the application of high doses to the tumor volume. The corresponding irradiation techniques require on the one hand adequate field shaping devices as multileaf collimators (MLC) and on the other hand accurate patient setup, immobilization and, in the ease of fractionated radiotherapy, exact repositioning. This is particularly true, if radiosensitive organs are situated close to the target.

The task of the two working groups is the development of new techniques and hardware components for radiation therapy. Main issues are the improvement of patient setup accuracy and motion control during treatment, the development and implementation of electro-optical devices, image processing tools for treatment validation and verification and the development of electro-mechanical devices for field shaping conformal radiotherapy.

Fixation, immobilization and positioning

In radiotherapy or radiosurgery, safety margins have to be included in the target volume to account for patient misalignment during setup, involuntary patient movements during therapy and organ motion, that can cause rather complex possibilities of movements of the target point. Minimising this safety margin allows a more conform therapy with decreased field sizes and the delivery of higher doses to the tumor.
Whereas the bony structure of the skull realizes a fairly good immobilization for intracranial structures, the situation for extracranial targets is much worse. Especially for thoraco-abdominal targets, periodical movements, organ motion and deformation compromises the aim of a highly accurate and reproducible positioning of the patient.

Due to individualized motion patterns, a generalized consideration in the treatment and planning process is not adequate. Thus the actual work focusses on the fields of immobilization and fixation as well as optical tracking and monitoring of the patient position.

For extracranial targets, a stereotactical fixation device has been developed in cooperation with Howmedica Leibinger in Freiburg and the Health Sciences Center in Tucson, University of Arizona, USA. It is designed especially for treatment demanding exceptional high spatial accuracy, e.g. lesions in the immediate vicinity of the spinal cord.

For single-fraction irradiation of intracranial lesions, stereotactic immobilization techniques have been developed. These techniques are generally based on invasive stereotactic frames, that define reference coordinate systems for imaging, therapy planning and patient positioning. The positioning and immobilization accuracies for these invasive frame based techniques are better than 1 mm. For fractionated radiotherapy of head and neck lesions, non invasive head holder systems are frequently used for patient setup and immobilization.

The problem of fixation accuracy of patients in head masks is discussed in the literature. Depending on the mask material and the molding techniques, the achievable accuracy for immobilization and repositioning is in a range of several mm. This spatial uncertainty does not allow a fractionated irradiation scheme for lesions in the immediate vicinity of critical structures like the brainstem, optic nerves etc. Therefore, non-invasive immobilization and positioning devices with a high spatial accuracy and patient tolerability have to be developed. Furthermore, these systems should not prolongate the treatment time and the complexity of manual interactivity.

For high precision fractionated radiotherapy in the head and neck region, an integrated videogrammetry based system (PPSU) has been developed [1,2,3]. Two calibrated CCD-cameras generate continuously stereoscopic images of external markers. The markers are attached to a dento-maxillary fixation system which fits perfectly the teeth of the patients upper jaw. The stereoscopic images are processed and allow the calculation of the markers position in space. Under the assumption of rigid body mechanics between markers and target point, the tracking of the markers position reveals the corresponding target point position. For a default position of the target point, i.e. linac isocenter, the actual deviation can be monitored in standard video frequency (25 frames per second).

The described patient positioning sensor unit (PPSU) can serve multiple purposes. The measurement system can be used to determine and display the position of the target point relative to the isocenter during patient setup. Furthermore it can be used to detect and display target point displacements caused by patient motions during therapy. User defined limits in all 6 degrees of freedom can serve as interrupt criterion for the therapist.

The optional positioning system serves as an automatic high precision device for patient setup during subsequent irradiations in fractionated therapy. Therefore the measured data of target point displacement are input data for the movement of the tabletop. Beyond this ability during the setup procedure, the positioning system can be used for online compensation of the motions detected during...

Figure 1: Extracranial fixation device for the trunk of body.
therapy. The overall positioning accuracy of the complete system was determined to be 0.6 mm.

This high positioning accuracy allows for a significant decrease of the commonly added safety margins. In consequence, the volume of the tumor-surrounding healthy tissue, that will be irradiated as an effect of the safety margins, can substantially be reduced.

An additional important application of video-based positioning and tracking systems are breast irradiations. The use of intensity modulated radiotherapy techniques is a promising approach to improve radiotherapy of breast cancer. But it is very important to position the breast irradiated as precise as possible performing new precise irradiation techniques. Female breast is a deformable organ and it is not allowed to put thick material on breast skin because of the danger of irradiation damage of the skin. Therefore it is a challenge to position the female breast in a precise and reproducible way during the treatment course.

In the framework of a breast cancer project we are investigating the feasibility of a video-based positioning system for breast cancer treatments.

The overall goal of these activities is to provide the tools for adaptive radiotherapy, which is the application of navigation concepts to conformal radiotherapy.

Conformal irradiation techniques
Besides accurate immobilization and positioning of the patient, it is important to tailor the delivered dose distribution with respect to the target volume and the organs at risk. Field shaping in combination with intensity modulation allows the delivery of arbitrary dose distributions. This conformity of the tumor is realized by using compensators or, with more flexibility, by using multileaf collimators. The MLC consists of 40 pairs of tungsten leaves, driven by 80 DC motors. With a leaf width at isocenter of 1.6 mm, the maximum field size is 73 x 64 mm. With a maximum leaf overtravel of 24 mm, a max. leaf speed of 15 mm/sec and a micro-controller based leaf position verification with a accuracy < 0.5 mm, the MLCs specifications meets the demands for dynamic field shape and intensity modulated radiotherapy (IMRT). The clinical implementation of the MLC at DKFZ is completed now. Furthermore the development was commercialized by MRC, Heidelberg and the MLC is now on market available.

In 1998 we started with IMRT patient treatments as one of the first centers in Europe using the build-in MLC of our treatment facility. Because of the complexity of this treatments, individual treatment verifications are mandatory. For that reason several dosimetric phantoms have been developed. An important feature for clinical feasibility and clinical practice of a new treatment procedure is the time required. Therefore a software has been developed to accelerate the process of verification and evaluation of individual patient treatments, which was one of the most time-consuming process in treatment planning and preparation. Another way to reduce treatment time is to change the dose fractionation scheme slightly [4].

Furthermore it is planned to implement IMRT using the DKFZ Micro MLC.

This is the next logical step on the way to our goal to implement patient case specific IMRT-tools in order to improve radiotherapy treatments.

CoRA – A new Cobalt Radiotherapy Arrangement
Linear accelerators (Linac) are the standard irradiation treatment units in clinical routine for both radiotherapy and radiosurgery. The available infrastructure in developing countries together with technical and economical arguments allow in most cases only the use of isotope units for radiotherapy. On the other side there is a natural interest in modern conformal treatment techniques in these countries. However, the technology of todays gamma teletherapy units and modern treatment methods are mutually exclusive in most cases. Isotope units can not be utilized in combination with multileaf collimators (MLC) due to their large source sizes and the mechanical conditions of these units do not allow stereotactic radiosurgery. The Gamma-Knife and the Rotating Gamma Unit exclusively designed for radiosurgical treatments are only applicable for cranial lessons. So in developing countries the postulation for a multifunctional treatment unit is existent based also on financial limitations.

Therefore we developed a new concept of an irradiation system which combines the advantages of the Gamma Knife and the Linac [5]. It allows the delivery of fractionated radiotherapy, usage of MLC for irregular field shaping, simultaneous irradiation form different directions, geometrical accuracy etc.. The unit is designed as an isocentric device. Stereotactic treatment techniques will also be possible. The source holders including the sources are fixed on a swivel-mounted arc in such a way that their beam axes intersect at the isocenter of the unit (see fig. 2). The system gives also the possibility to attach beam limiting devices like MLC. For the first time CoRA allows the irradiation of more than one irregular field at the same time for all target positions.

![Figure 2: Schematic picture of CoRA indicates the components.](image)

It was found that the System CoRA and the CoRA arc technique will be suitable for treatments of cranial target volumes. In comparison with the multiple arc technique no drawback is noticeable due to the reduced number of arcs. The CoRA arc technique has the advantage of simulta-
neous beam application, e.g. the ability for an optimization of the treatment time. In the future CoRA perhaps will provide a treatment modality suitable for both radiotherapy and radiosurgery in developing countries.

**Development of a new stereotactic system for neurosurgery**

Stereotactic techniques allow to place surgical instruments (i.e. biopsy needles) or radioactive implants accurately and reproducibly at a certain target point and to move this instruments along a selected trajectory with minimal damage to overlying structures.

In conventional stereotactic neurosurgery a base ring is mounted to the patient to fix and immobilize the head of the patient and to define a coordinate system to register diagnostic images. Further it is used to fix the target system which facilitates the accurate placement of the instruments.

Nevertheless there are a few drawbacks of these conventional systems. Not all trajectories which are useful from a clinical point of view are technically feasible with such conventional systems. Furthermore conventional arc systems are not adaptable to the whole body stereotactical neurosurgery. These systems are restricted to the area to the head.

To overcome this disadvantages computer controlled robots have been developed or adapted for clinical use. Meanwhile such robots are commercially available. A major drawback of robotic systems are the high costs. Beside this the absolute accuracy of robotic systems is not sufficient for stereotactic neurosurgery.

In cooperation with Prof. Dr. V. Sturm, Dept. for Stereotactic & Functional Neurosurgery, University of Cologne and an industrial partner (Zettmess GmbH, St. Augustin), we are developing a new stereotactical system for neurosurgery based on a commercial 6 axes 3D measuring system. Such a system is similar to a passive manipulator arm (see fig. 3). The aim of the project is to adapt that system to the clinical constraints and to provide a prototype for clinical studies.

The newly developed system will be much more cost-effective as robotic systems and more flexible as conventional arc systems. Furthermore it is also suitable for whole body stereotaxy.

Because certain constraints in stereotactical neurosurgery are similar to the constraints in stereotactical radiosurgery our experience in the field of stereotactical radiosurgery is transferable to the new project.

**Patient couch system**

In cooperation with Prof. Dr. V. Sturm, Dept. for Stereotactic & Functional Neurosurgery, University of Cologne an “operating room couch-system” was developed so that the patient remains on a special couch which can be moved from every diagnostic instrument (CT, MRT, x-ray, etc) to the treatment units (operating room, linac, etc) with the help of trolleys. Adapter plates were constructed to fit the patient couch to the different couches of the various machines. A newly developed operating room table allows to move the patient from a basic height of appr. 70 cm to a max. height of appr. 125 cm. The advantage of this table is that the surgeon can operate the patient from the occipital side while the surgeon is sitting on his chair and the patient is lying on the couch in the supine position. Special materials such as kevlar (patient couch) make it possible to treat the patient e.g. inside the MRT.

The first patient treatments on the new couch system will start in Köln in May 2001.

**Photodynamic Therapy (PDT) and Diagnosis (PDD)**


In cooperation with: Dr. J. Gahlen, Dept. of Surgery, University of Heidelberg; Dr. P. Kremer, Dept. of Neurosurgery, University of Heidelberg; Dr. A. Kübler, Dept. of Oral and Maxillofacial Surgery, University of Heidelberg; Dr. H. Sinn, Dr. A. Wunder, DKFZ, Division of Radiochemistry and Radiopharmacology; Dr. U. Zillmann, DKFZ, Central Animal Experiment Facility

Photodynamic Therapy is a novel therapeutic modality for the treatment of tumors. A locally or systemically administered light-sensitive substance (photosensitizer or fluorescent dye) selectively accumulates in tumor tissue. When excited by light with an appropriate wavelength, the photosensitizer molecules emit fluorescence light which makes the tumor visible or delineates tumor margins (diagnosis), and accordingly, singlet oxygen is produced by energy transfer processes, which kills the treated tumor cells (therapy).

In cooperation with different departments of the Heidelberg University clinic, new photosensitizers and applications are investigated.

Main subjects of interest are the investigation of the photophysical and pharmacokinetic properties of newly developed macromolecular photosensitizers and fluorescent dyes, the optimization of therapy and diagnosis and the technical support of the clinical partners during the implementation of photodynamic therapy in the clinic.

Publications (* = external co-author)


Characterization of PDT-relevant properties of the photosensitizer mTHPC coupled to polyethylene glycol

To further enhance the pharmacokinetic properties of the photosensitizer mTHPC, a derivatization technique to couple mTHPC covalently to polyethylene glycol (PEG) has been developed by the Division of Radiochemistry and Radiopharmacology of the DKFZ.

For this new substance, the preservation of absorption and fluorescence properties could be found. In animal experiments, mTHPC-PEG showed to have an increased circulation half-life (in our model t = 20 h) compared to free mTHPC, as well as an enhanced tumor uptake. After 72 h, 20% of the initially applied dose of radioactively labeled mTHPC-PEG could be detected in the tumor (fig. 1). This was a 40-fold concentration of sensitizer compared to muscle and a 10-fold concentration compared to skin.

However, cell culture experiments and therapy experiments in animal models showed a decreased photodynamic efficiency of mTHPC-PEG compared to mTHPC. The molecule linking mTHPC with PEG could be identified as responsible for inferior cell uptake of mTHPC-PEG.

A new substance with a different linker molecule was successfully developed and is currently investigated in cell culture and animal experiments. Preliminary results indicate that its efficiency is comparable to that of the low molecular mTHPC.

Photodynamic therapy with mTHPC in oral and maxillofacial surgery

Non-melanomatous skin tumors are one of the most frequent tumors in the white population and mainly caused by cumulative exposure to solar ultraviolet B radiation. On account of this, about 80 percent of all non-melanomatous skin tumors are located on the arms or the head and neck. Standard treatment for most tumors is surgical resection, with often only a moderate cosmetic outcome.

In cooperation with the Dept. of Oral and Maxillofacial Surgery, University of Heidelberg, the effect of photodynamic therapy on primary non-melanomatous skin tumors of the head and neck (squamous cell cancer, basal cell cancer, actinic keratosis, Bowen’s disease) was tested in a prospective clinical trial. In this study meta-Tetrahydroxyphenylchlorin (mTHPC / Foscan™), a systemic photosensitizer of the second generation, was applied. Patients were injected 0.15 mg/kg or 0.10 mg/kg mTHPC 96 hours prior to laser light exposure. Light was delivered via fibres by an argon-dye laser at 652 nm, 100 mW/cm² and a light dose of 5 – 20 J/cm².

25 patients with a total of more than 150 non-melanomatous skin tumors and a mean follow up of 15 months (ranging 6 to 26 months) were treated. Within several days tumor necrosis appeared followed by wound healing within 4 to 8 weeks, leaving only minor scars behind (fig. 2). Seventy tumors showed a complete response with an excellent cosmetic outcome and only three basal cell cancers responded with partial success. No adverse events occurred. The therapy was supported by a high degree of patient satisfaction.

By choosing the correct drug and light dosage, a selective tumor necrosis can be obtained. PDT using mTHPC seems to be a promising new and safe treatment modality for the treatment of primary non-melanomatous skin tumors of the head and neck which can substitute surgical therapy, offering an even better cosmetic outcome.

In another phase II study 22 patients with primary squamous cell cancer of the head and neck were treated with photodynamic therapy. Again the response rates were comparable to those of standard surgical therapy, while the cosmetic and functional outcome was much better.
Laser-induced fluorescence detection of glioma using aminofluorescein-labeled serum albumin (AFL-HSA)

Surgical treatment of malignant gliomas is limited due to the difficult identification of the tumor margins even under the operating microscope and the diffuse migration of malignant cells into the surrounding brain. Although even complete removal of the solid tumor mass cannot cure the disease, patients still benefit in terms of quality of life and survival time. In most cases, residual tumor and tumor recurrence develop from these residual macroscopic parts of the tumor margins, which can be unequivocally detected by early postoperative and following-up MR images.

In cooperation with the Dept. of Neurosurgery, University of Heidelberg, the use of aminofluorescein coupled to human serum albumin (HSA) as a fluorescent tumor marker for intraoperative visualization of the tumor margins was investigated.

In cell and animal experiments it could be shown that significant amounts of the applied dose of AFL-HSA were taken up by proliferating cells. In a C6 glioma rat model the fluorescent dye could be used to identify the tumor margin, using laser light to excite fluorescence.

Up to now, three patients have been successfully treated using AFL-HSA as intraoperative tumor marker (fig. 3). Patients were injected with AFL-HSA four to five days prior to surgery. During the operation the fluorescein-contrasted tumor was well visible when inspected with the naked eye after activation with laser light and was clearly delineated against the surrounding brain. A clinical study investigating the use of AFL-HSA for neurosurgery is in preparation.

Publications (* = external co-author)

Fig. 2: Basal cell cancer on the nose before photodynamic therapy (left) and 3 months after treatment (right)

Fig. 3: Glioma intraoperative 72 h after injection of AFL-HSA. Left: white light, right: fluorescence after laser light excitation.
Biophysics and radiation therapy physics (E0408)
G.H. Hartmann, F. Fölsch, D. Haspel, R. Hofmann, O. Jäkel, C. Karger

There are three projects that were carried out on a larger scale in cooperation with other groups within and outside the Division of Medical Physics: the medical-physical issues to the German Heavy Ion Therapy Project (see E0408), the project aiming at an implementation of a total quality management system to all radiotherapy activities within the division, and a project to develop motor driven multi-leaf collimators and to introduce them into clinical practice. Two other activities are located totally within the working group: the development and application of array detectors for 2D and 3D dosimetry, and a research project to study long time radiation damage after radiosurgery in an animal model.

1. Cooperation projects
1.1 Implementation of a total quality management system (TQM) for the radiotherapy activities of the division
Many aspects of a quality management system of software related items in radiotherapy planning have already been addressed under E0401. In addition to that, a TQM must address each single part of the chain of procedures involved in a course of radiotherapy, starting from image data acquisition, then going through creating the patient model (including patient related coordinates), radiotherapy planning, patient positioning and finally coming to the beam delivery itself. A formal structure has been established to accomplish this task, and this structure has been successfully applied in the area of radiosurgery and heavy ion therapy. It remains to extend this concept to any radiotherapy activities within the division.

1.2 Introduction of motor driven multi-leaf collimators into clinical practice
The introduction of multi-leaf-collimators (MLC) in radiotherapy has substantially initiated new methods with a high tumor conformation of the delivered radiation dose. The development of adequate MLC devices (manual or motor driven) is one of our central activities aiming at an application of our MLCs under routine clinical conditions up to the end of this year.

2. Development of array detectors for 2D and 3D dosimetry

The dose distribution achieved by the new radiation therapy techniques (conformal radiotherapy, IMRT, raster scan particle therapy) are complex and three dimensional in shape. The general problem associated with that is to verify the correct (i.e. the pre-planned) generation of such dose distributions. Adequate 3D measuring techniques are therefore required. Our concept is to accomplish a 3D measurement by a high number of small detectors distributed in an appropriate way in space such as segmented array detectors using liquid detector material (liquid ionization chamber). We currently also develop an electronic acquisition system for that of up to thousand simultaneously measuring channels and suitable phantoms.

3. Long time radiation damage after radiosurgery in an animal model

High single doses are particularly critical with respect to create a necrosis in the brain. The aim of this research project is to quantitatively and systematically determine long time radiation damage as observable by MR investigations after small sized dose volumes in the rat brain. For this purpose a radiosurgery irradiation technique was developed applicable to the rat. In a pilot experiment irradiations were performed with the 3 mm collimator applying dose values from 20 - 100 Gy to the left part of the brain. Changes of MR signals were observed over a time period of 18 months. Following this, a preliminary dose effect curve as well as a value for D50 were determined (Fig. 1).

The histological evaluation revealed that the changes were limited to the small sized dose volume. Based on this pilot experiment, the main irradiation experiment followed using 110 animals to obtain more significant data. These results were expected for this year aiming at a reference for further experiments with modified irradiation conditions. As an example, an irradiation experiment was performed applying carbon ions instead of X-rays from the linear accelerator. Again, results of this experiment with respect to the associated relative biological effectiveness were expected within this year.

Publications (* = external co-author)


**Heavy Ion Therapy Project (E0409)**

O. Jäkel, P. Heeg, C. Karger, U. Oelfke

In cooperation with: PD J. Debus, Clinical Cooperation Unit Strahlentherapeutische Onkologie, DKFZ; Prof. M. Wannenmacher, Radiological University Hospital Heidelberg; Prof. G. Kraft, Department for Biophysics of the Gesellschaft für Schwerionenforschung (GSI), Darmstadt

The aim of the heavy ion therapy project is to investigate, if the special physical and biological properties of heavy ions can be translated into an increased local control of malign tumors. The special feature of heavy ions in radiotherapy is, that they have a limited range in tissue that can be controlled by their energy and that their radiobiological effect in tissue is strongly enhanced, as compared to conventional X-rays.

In a joint research project of the radiological university hospital Heidelberg, the German heavy ion research laboratory (GSI) and the DKFZ, a therapy facility for carbon ions was established at GSI. Between December 1997 and November 2000 in total 78 patients mostly with malign tumors of the base of skull were treated with carbon ions in various clinical studies. The project group at DKFZ is responsible for the medical physics aspects. This includes clinical dosimetry, treatment planning, patient positioning and quality assurance for these issues. Besides improvements and developments of new techniques for the clinical routine at GSI, the project group is also involved in the preparation and design of a clinical heavy ion center at the university hospital Heidelberg within a strategy fund.

The ongoing projects in the field of dosimetry are the precise measurement of various correction factors within the dosimetry protocol to improve the precision of dose measurement and the optimization of verifications of the patient specific treatment fields, to allow an efficient control of dose distributions prior to the begin of therapy. This also includes modified techniques that are necessary for the use with a rotating gantry.

In the field of treatment planing, the planning software is constantly being developed further, to allow a more efficient planning process. This is necessary to cope with the much higher number of patients to be treated at a clinical therapy facility. The modifications of the optimization algorithms aim at a further improvement of dose conformation. The existing software will also be used to investigate the principal possibilities and limits of this new therapy when applied to new tumor localizations and indications.

For a more flexible patient positioning, a treatment chair is being developed, to gain an additional degree of freedom in the treatment angles. Furthermore, the X-ray-units for position verification of the treated patients are evaluated to retrospectively assess the accuracy of positioning and their implications for the treatment. The currently used positioning methods for the head and neck region are being modified for future applications in the trunk of the body.

The quality assurance procedures are being developed further in all areas. They allow to check the precision of the techniques used in the various fields and to constantly

maintain a high level of quality by the use of constancy checks. New test methods are especially important for the official approval of new techniques by the authorities (e.g. irradiations in the trunk of the body or use of the treatment chair).


Publications (* = external co-author)


