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Radiation and Osteosynthesis

Dosimetry on an Irradiation Phantom

Peter Stoll[1], *Rüdiger Wächter*[1], *Norbert Hodapp*[2], *Wilfried Schilli*[1]

[1] Dept. of Oral and Maxillofacial Surgery (Head: Prof. W. Schilli, M.D., D.M.D.), University of Freiburg, West Germany
[2] Dept. of Radiology (Former Head: Prof. M. Wannenmacher, M.D., D.M.D.), University of Freiburg, West Germany

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Summary

An irradiation phantom was used to measure dose increases using the backscatter of different materials (titanium, steel, lead, aluminium). Telecobalt-60 and 8-MV photons were used for the irradiation. The irradiation dose was measured by means of a defined X-ray film blackening. The most important parameter was to find out whether under simulated conditions, undesirable hot spots occur. We were able to demonstrate that a 12.5 to 16% increase in the radiation dose can be observed for titanium and steel at a distance of 0.45 mm from the metal specimen. A comparison between titanium and steel did not demonstrate a relevant advantage for titanium. Therefore, adjuvant percutaneous radiation therapy should not have any influence on the life of the implant, if the soft tissue layer is of sufficient thickness. The available literature is reviewed and presented in tables.

Key words

Radiation – Backscatter – Irradiation phantom – Osteosynthesis – Implants – Mandibular reconstruction plate

Introduction

Since the beginning of the 80's, bone defects following radical tumour surgery have been bridged by osteosynthesis. There are various techniques and materials which may be applied (*Austermann* et al., 1977; *Ewers* and *Joos,* 1977; *Reuther* and *Hausamen,* 1977; *Schmelzle* and *Schwenzer,* 1977; *Spiessl,* 1978; *Kärcher* and *Eskici,* 1986). The titanium-coated hollow screw reconstruction plate (THORP) system developed by *Raveh* et al. (1981, 1984) may be included in this series as a new method of reconstruction.
However, some authors (*Schmelzle* and *Schwenzer,* 1982) consider subsequent tumour irradiation in the presence of metal implants to be problematic, especially in exposed areas, such as the mandible. Dose enhancement may arise as a result of backscatter at the interface with denser material. These areas of increased radiation exposure, known as hot spots, are considered clinically relevant when in tissue cross-section they exceed an area of approx. 2 cm^2 and attain dose values of more than 100% of the intended dosage of the target volume (ICRU-Report 29). For this reason *Schwartz* et al. (1979) favoured a reconstruction plate made of Dacron urethane.
The interface problem between more and less radiodense materials has been known for a long time. Measurements for a depth dose curve at these interfaces of different materials have already been described (*Hine,* 1951; *Dutreix* et al., 1962, 1964; *Wambersie* et al., 1965; *Dutreix* and *Bernard,* 1966; *Spiers,* 1966; *Wall* and *Burke,* 1970; *Manegold,* 1970; *Berger,* 1971; *Kulkarni* et al., 1972; *Gibbs* et al., 1976; *Murthy* and *Lakshmann,* 1976; *Gagnon* and *Cundiff,* 1980). In order to exclude errors in measurement, *Rosendahl* and *Kirschner* (1979) attempted to calculate the dose of energy absorbed using the Monte Carlo method.
Does a danger of increase dosage (hot spots) exist when using metal reconstruction plates during irradiation of head and neck tumours? Are there further differences related to the density of the material and which may, as a result, possess other characteristics with respect to transmission and backscatter? Are there differences reflecting the type of radiation used?
To answer these questions still open, it seemed prudent to perform the simulations on an irradiation phantom under reproductable conditions.

Material and Method

The investigation was performed using 4 different metals, each subjected to telecobalt 60 irradiation (Philips cobalt device: 1.3 MeV photons) and 8-MV photon irradiation (Philips Linac SL 75/20). The field size was 20 × 20 cm^2, the focus surface distance 80 cm and 100 cm, respectively.
1. Titanium (pure)
2. Steel (DIN 4435)
3. Lead (pure)
4. Aluminium (pure)

The metals were used in the form of 2 and 3 mm thick square plates with an edge length of 5 and 6 cm, respectively. To determine the influence of screw holes, customary stainless steel and titanium AO-reconstruction plates were examined as well. Edge effects were investigated using strips of steel and titanium, which differed from the reconstruction plates only in that they did not have any holes.
In preliminary tests, the angle of the incident beams was varied in order to evaluate any possible effects resulting from a deviation from the perpendicular.
The effects to be examined were limited to the immediate vicinity of the metal/tissue interface (under 2 mm). This complicated both the measurements made using ionization chambers and with thermoluminescence dosimeters (TLD) (*Frößler* et al., 1971) since the measured volumes in both methods do not correspond to the dimensions of the areas to be measured. Customary TLDs have a diameter of 1 mm. If these have to be protected from moisture in simulations with a plastic coat, the diameter is increased up to 1.8 mm.
We thus selected an experimental arrangement of the following construction (Fig. 1): water and polystyrene were chosen as a tissue substitute since muscle and other soft-tissues have the same physical density as these materials. The

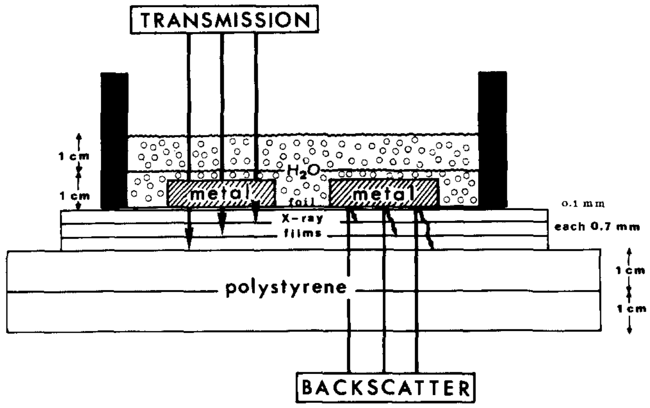

Fig. 1 Schematic cross section of the irradiation phantom.

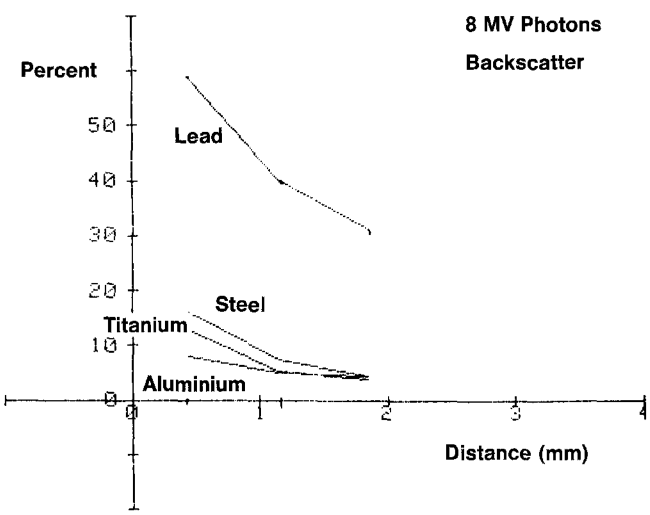

Fig. 2 Backscatter: Relative dose enhancement (in percent) in front of the metal (cobalt-60 irradiation).

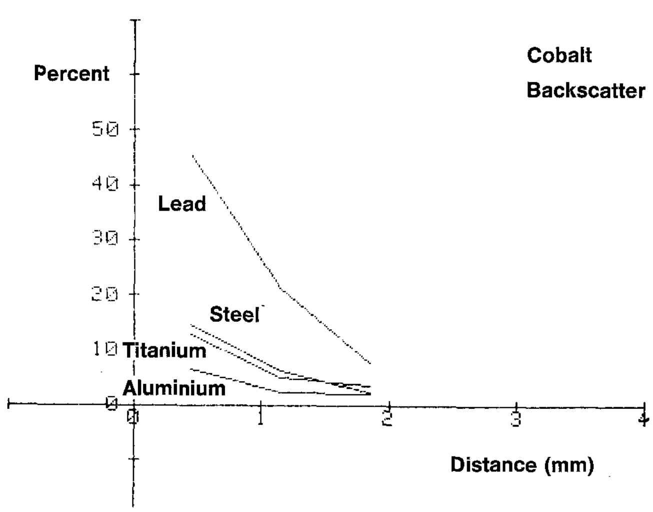

Fig. 3 Backscatter: Relative dose enhancement (in percent) in front of the metal (8-MV photon irradiation).

metal specimens lay in a water-bath on plastic foil 0.1 mm thick. Placed under the water-bath one on top of the other were 3 originally packed Kodak-X-Omat-V2 films on 1 cm (for cobalt irradiation) or 2 cm thick (for 8-MV photon irradiation) polystyrene plates. To determine the backscatter effect irradiation was conducted from below, to determine the absorption it was conducted from above. The distance in water was also 1 cm for cobalt irradiation and 2 cm for 8-MV photon irradiation. The film packaging and the plastic foil at the bottom of the water-bath led to measuring points (middle of the film) of 0.45 mm, 1.15 mm, and 1.85 mm either in front of or behind the metal test object.

The dose in front of or behind the metal specimens was registered by film blackening. As the metal specimens had enough space between them there were large enough areas of undisturbed film blackening which could be compared with the areas at the edges or the perforation or with the regions behind or in front of the metal surfaces. Quantity could be obtained when calculating the ratios of the relative dose values on the depth dose curves of the two irradiation devices which corresponded to the film blackening on films registered in a polystyrene phantom parallel to the beam direction and which had the same optical density as the points of interest of the experimental films. For all optical densities mean values of several points were taken which were measured on places where constant dose distribution could be assumed.

The mean of several measured values taken independent of the metal test objects was used as a reference value.

Results

Neither the size nor perforation of the individual test objects showed essential irregularities on backscatter. The direction of transmission was seen to depend on the thickness of the material used. The metal/screw hole interface behaved like the interface at the edges. In the preliminary tests, when varying the angle of the incident beam (deviation from the perpendicular to an angle of 30°) there proved to be no significantly measurable difference in dose increase in front of or dose decrease behind the metal specimen.

The quantitative evaluation of backscatter when using plates 2 mm thick at a distance of 0.45 mm for cobalt-60 irradiation was 46% of the applied dose for lead, 14.5% for steel, 12.5% for titanium, and 7% for aluminium. When using 8-MV photons the following increased doses could be recorded: 58% for lead, 16% for steel, 12.5% for titanium, and 8% for aluminium. At a distance of 1.85 mm from the metal test objects the values dropped to 8%, 2.5%, 3%, and 2.5% for cobalt-60 irradiation and to 31%, 5%, 4%, and 4.5% for 8-MV photon irradiation (Figs. 2 and 3, Tables 1 and 2 respectively).

The dose values behind the metal plates (transmission) at a distance between 0.45 mm and 1.85 mm already approached the values determined corresponding to the absorption of the material thickness asymptotically (Figs. 4 and 5).

Discussion

The influence of metal implants and metallic dental materials on dose distribution when applying radiotherapy has already been investigated by a series of authors (*Ritter* and

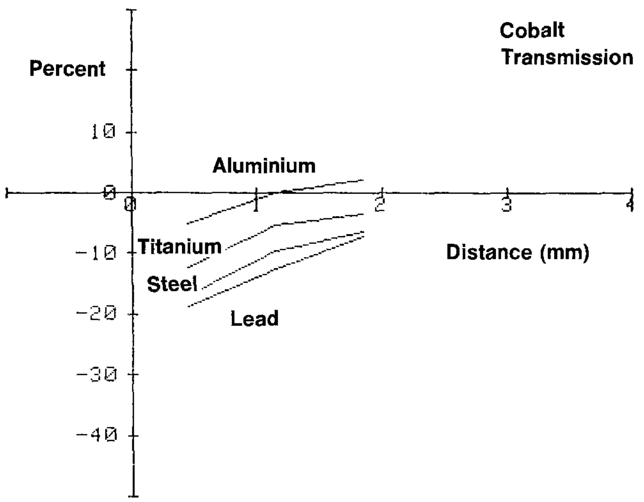

Fig. 4 Transmission: Relative dose decrease (in percent) behind the metal (cobalt-60 irradiation).

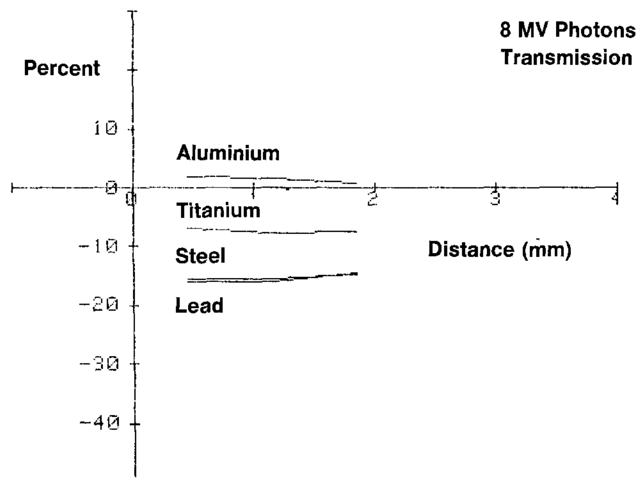

Fig. 5 Transmission: Relative dose decrease (in percent) behind the metal (8-MV photon irradiation).

Schütz, 1967; *Maerker* et al., 1976; *Scrimger,* 1977; *Rosendahl* and *Kirschner,* 1979; *Thambi* et al., 1979; *Sailer,* 1980; *Tatcher* et al., 1984; *Hudson* et al., 1984; *Ebbers* et al., 1985; *Farman* et al., 1985; *Eichhorn* et al., 1986; *Mian* et al., 1987). In these investigations backscatter caused an increase in dose of between 20% and 80% (*Gibbs* et al., 1976; *Sailer,* 1980; *Tatcher* et al., 1984; *Eichhorn* et al., 1986) for metals and types of radiation beams in common use. Examined especially were steel, titanium, amalgam, and gold (Table 3). Lead (periodic number: 82; density 11.3 g/cm^3) as a radio-opaque medium and aluminium (periodic number: 13; density 2.7 g/cm^3) as a relatively radiolucent medium were also investigated by several authors simultaneously, with a view to comparing and delimiting the various metals.

The apparently greater dose enhancement in front of the metal plates measured by *Sailer* (1980) and by *Tatcher* et al. (1984) compared to ours can be readily explained. If one considers the dose enhancement in the graphs at a distance of 0.45 mm in front of the plate, the results of the measurements correspond almost exactly. In this context, we must also assume in our investigations that the dose elevations immediately in front of the metal (<0.45 mm) increase asymptotically. It proves all the more important in the comparison of different investigations to note the measuring points in front of the metal bodies. Unfortunately, one often finds only very indefinite data on the actual measuring points in front of the metal test objects (Table 3), thus reducing the significance of such investigations for the reasons mentioned above.

The relatively smaller enhancement for titanium (7%) in front of the plate given by *Frößler* et al. (1975) and *Maerker* et al. (1976) for Vitallium may be explained by the greater volume of the TLDs. This means that "distant areas" in front of the plate are already taken into account and integrated. Nevertheless, we can support their opinion that radiotherapy is also possible in the case of titanium and Vitallium implants. The calculations made by *Rosendahl* and *Kirschner* (1979) and *Mian* et al. (1987) agree with our results (*Stoll* et al., 1989) very closely, although it should be noted that on extrapolating our measurements at a distance of 0.03 mm in front of the metal test object, we would observe a greater dose enhancement ($>16\pm2$%). *Mian* et al. (1987) found corresponding results in their investigations between calculation and measurements.

Under cobalt-60 irradiation, the comparison between titanium and stainless steel plates shows no decisive radiophysical advantage for titanium. As far as irradiation with 8-MV photons is concerned titanium (12.5%) proved slightly better than steel (16%). With regard to the degree of relative dose enhancement the angle of the incident beam appears to be of relatively minor importance, as has already been described by other authors (*Manegold,* 1970; *Rosendahl* and *Kirschner,* 1979; *Sailer,* 1980; *Ebbers* et al., 1985). However, it must be presumed that in the case of irradiation perpendicular to the metal test object, the phenomena

Table 1 Backscatter: Relative dose enhancement (in percent) at 3 defined measuring points in front of the metal under cobalt-60 irradiation

Metal	Distance (mm)		
	0,45	1,15	1,85
lead	46	20	8
steel	14,5	6	2,5
titanium	12,5	5	3
aluminium	7	2,5	2,5

Table 2 Backscatter: Relative dose enhancement (in percent) at 3 defined measuring points in front of the metal under 8-MV photon irradiation

Metal	Distance (mm)		
	0.45	1.15	1.85
lead	58	40	31
steel	16	7.5	5
titanium	12.5	5	4
aluminium	8	5	4.5

Table 3 Dose enhancement as a result of backscatter using different metal implants. Survey of measurements.

Author	Year	Type of Irradiation	Single =(S) Opposed =(O) beam direction	Metal	Relative Dose Enhancement in Front of Metal (%)	Distance Between Measuring Point and Metal (mm)	Method of Measurement
Frößler et al.	1975	cobalt-60	S	titanium	7	"in front of the titanium plate"	TLD
Gibbs et al.	1976	6-MV photons	S	gold	75	"directly on the plate"	ionization chamber and film
				amalgam	55		
			O	gold	30		
				amalgam	20		
Maerker et al.	1976	cobalt-60	S	vitallium	9	"directly in front of the plate"	TLD and film
Scrimger	1977	cobalt-60	S	titanium	10	"measured directly at interface"	ionization chamber
				lead	72		
				tin	50		
				brass	32		
				steel	25		
				titanium	12		
Rosendahl and *Kirschner*	1979	cobalt-60	S	titanium	16±2	0.03	calculation (Monte Carlo method)
Thambi et al.	1979	cobalt-60	S	lead	80	"directly at lead foil"	TLD
			O		67		
Sailer	1980	8-MV photons	S	lead	73	"measured directly at interface"	ionization chamber
				steel	30		
				aluminium	13		
Hudson et al.	1984	8-MV photons	S	steel	20	"measured at interface"	film
				copper	40		
Tatcher et al.	1984	cobalt-60	S	Vitallium	43	"measured at the metal plate"	film
				steel	33		
				titanium	26		
Farman et al.	1985	cobalt-60	S	gold	21	"region of interproximal gingivae at the phantom"	TLD
				amalgam	19		
				aluminium	11		
				steel	8		
Eichhorn et al.	1986	cobalt-60	S	Küntschernails;	18–35	"at metal implant"	TLD and ionization chamber
		10-MV photons		compression plate	45		
Mian et al.	1987	cobalt-60	S	titanium	15	"measured directly at interface"	ionization chamber and calculation (Monte Carlo method)
		6-MV photons			14		
		25-MV photons			11		
Stoll et al.	1989	cobalt-60	S	lead	46	0.45	film
				steel	14.5		
				titanium	12.5		
				aluminium	7		
		8-MV photons		lead	58		
				steel	16		
				titanium	12.5		
				aluminium	8		

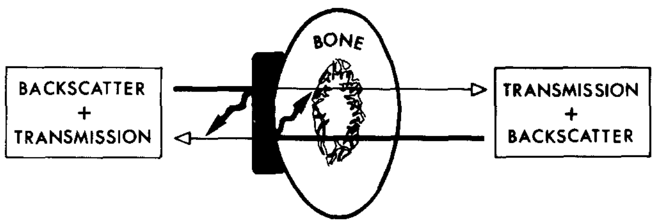

Fig. 6 Backscatter and transmission using opposed beam direction at the mandible.

of backscatter and decreased transmission at maximum intensity can be measured (*Tatcher* et al., 1984).

This means for postoperative irradiation: significant dose enhancement due to backscatter can be observed in a range of under 1 mm in front of the implanted metal plate. In most cases backscatter is compensated by employing the opposing field technique which reduces the dose behind the plate (Fig. 6). In this context *Gibbs* et al. (1976) were able to record the differences in dose enhancement in a comparison of single field and opposing field irradiation. Investigations on gold showed a 75 % elevation in the single field, dropping to 30 % at the same measuring point under opposing field irradiation. Care should be taken, however, in single field irradiation treatment where the implant is in the region of maximum dose, especially when this lies above the target volume dose and in fractionated schedules (*Ellis* et al., 1969, 1974) in which the biological effect of the dose is greater.

Irradiation damage to the integument as a result of an increased dose due to backscatter when inserting metal implants can only really occur in this small area. Therefore, if the soft-tissue layer is of sufficient thickness, adjuvant percutaneous radiation therapy should not have any influence on the life of the implant.

Conclusions

An irradiation phantom was used to measure dose increases using the backscatter of different materials (titanium, steel, lead, aluminium). Telecobalt-60 and 8-MV photons were used for the irradiation. The irradiation dose was measured by means of a defined X-ray film blackening.

The most important parameter was to find out whether under simulated conditions, the undesirable hot spots occur. We were able to demonstrate that a 12.5 to 16 % increase in the radiation dose can be observed for titanium and steel at a distance of 0.45 mm from the metal specimen. A comparison between titanium and steel did not demonstrate a relevant advantage for titanium. Therefore adjuvant percutaneous radiation therapy should not have any influence on the life of the implant, if the soft tissue layer is of sufficient thickness.

The available literature is reviewed and presented in tables.

References

Austermann, K.-H., R. Becker, K. Büning, E. Machtens: Titanium implants as a temporary replacement of mandible. J. Max.-Fac. Surg. 5 (1977) 167

Berger, M. J.: Absorbed dose near an interface between two media. In: National Bureau of Standards Report 10 550. Washington, DC (1971) 38

Dutreix, J., A. Dutreix, M. Bernard: Étude de la dose au voisinage de l'interface entre deux milieux de composition atomique différente exposés aux rayonnements γ du ^{60}Co. Phys. Med. Biol. 7 (1962) 69

Dutreix, J., A. Dutreix, M. Bernard, A. Bethencourt: Étude de la dose au voisinage de l'interface entre deux milieux de composition atomique différente exposés à des RX de 11 à 20 MV. Ann. Radiol. 7 (1964) 233

Dutreix, J., M. Bernard: Dosimetry at interfaces for high energy X and gamma rays. Br. J. Radiol. 39 (1966) 205

Ebbers, J., R. Kürten-Rothes, U. Ganzer: Metallplatten-Osteosynthese und Nachbestrahlung. Eine tierexperimentelle Studie. Laryng. Rhinol. Otol. 64 (1985) 32

Eichhorn, M., R. Gerlach, D. Salewski, G. Sommer: Thermolumineszenzdosimetrische Untersuchungen zum Absorptionsverhalten von Knochen ohne und mit Metallimplantaten. Strahlenther. Onkol. 162 (1986) 779

Ellis, F., B. M. Winston, J. F. Fowler, W. L. De Ginder: Three or five fractions per week: treated on alternate treatment days. Letter of the editor. Br. J. Radiol. 42 (1969) 715

Ellis, F., A. Sorensen, C. Lescrenier: Radiation therapy schedules for opposing parallel fields and their biological effects. Radiol. 111 (1974) 701

Ewers, R., U. Joos: Temporäre Defektüberbrückungen bei Unterkieferresektionen mit Osteosynthesemethoden. Dtsch. Zahnärztl. Z. 32 (1977) 332

Farman, A. G., S. Sharma, D. I. George, D. Wilson, D. Dodd, R. Figa, B. Haskell: Backscattering from dental restorations and splint materials during therapeutic radiation. Radiol. 156 (1985) 523

Fräßler, H., R. Engberding, H. J. Rauba, J. Schütz: Erfahrungen mit dem PTW Lithiumfluoridthermolumineszenzdosimeter. Röntgen-Praxis 24 (1971) 242

Fräßler, H., L. Springer, M. Wannenmacher: Dosismessungen bei Kobalt-Teletherapiebestrahlung im Mundhöhlenbereich nach Titanium-Metallimplantation. ZWR 84 (1975) 258

Gagnon, W. F., J. H. Cundiff: Dose enhancement from backscattered radiation at tissue-metal interfaces irradiated with high energy-electrons. Br. J. Radiol. 53 (1980) 466

Gibbs, F. A., B. Palos, D. R. Goffinet: The Metal/Tissue Interface Effect in Irradiation of the Oral Cavity. Radiol. 119 (1976) 705

Hine, G. J.: Scattering of secondary electrons produced by γ-rays in materials of various atomic numbers. Letter to the editor. Phys. Rev. 82 (1951) 755

Hudson, F. R., M. T. Crawley, M. Samavasekeva: Radiotherapy treatment planning for patients fitted with prosthesis. Br. J. Radiol. 57 (1984) 603

ICRU-Report 29: (International Commission on Radiation Units and Measurements): Dose specification for reporting external beam therapy with photons and electrons.

Kärcher, H., A. Eskici: Ergebnisse der Rekonstruktion mit Überbrücungsplatten nach tumorbedingten Unterkieferresektionen. Dtsch. Z. Mund-Kiefer-Gesichts-Chir. 10 (1986) 91

Kulkarni, R. N., V. Sundararaman, M. A. Prasad: The dose across a plane bone-tissue interface. Radiat. Res. 51 (1972) 1

Maerker, R., K. Würthner, J. Timmermann: Experimentelle Untersuchungen über die Dosisverteilung CO^{60}-Bestrahlung nach Draht- und Plattenosteosynthese. Fortschr. Kiefer- Gesichtschir. 21 (1976) 208

Manegold, K.: Über den Einfluß der Elektronenstreuung an Inhomogenitätskanten. Strahlenther. 140 (1970) 647

Mian, T. A., M. C. Putten van Jr., D. C. Kramer, R. F. Jacob, A. L. Boyer: Backscatter radiation at bone – titanium interface from high-ernergy X and gamma rays. Int. J. Radiation Oncology Biol. Phys. 13 (1987) 1943

Murthy, M. S. S., A. R. Lakshmanan: Dose enhancement due to backscattered electrons at the interface of two media. Radiat. Res. 67 (1976) 215

Raveh, J., H. Stich, F. Sutter, P. Schawalder: Neue Rekonstruktionsmöglichkeiten bei Unterkieferdefekten nach Tumorresektion. Schweiz. Mschr. Zahnheilk. 91 (1981) 899

Raveh, J., H. Stich, F. Sutter, R. Greiner: Use of the titanium coated hollow screw and reconstruction plate system in bridging of lower jaw defects. J. Oral Maxillofac. Surg. 42 (1984) 281

Reuther, J., J.-E. Hausamen: System zur alloplastischen Überbrükkung von Unterkieferdefekten. Dtsch. Zahnärztl. Z. 32 (1977) 334

Ritter, W., J. Schütz: Zur Frage zahnärztlicher Behandlungsmaßnahmen bei Tumorbestrahlungen. Dtsch. Zahnärztebl. 12 (1967) 586

Rosendahl, E. W., H. Kirschner: Änderung der Tiefendosis durch eine Titanendoprothese bei der ^{60}CO-Strahlentherapie. Strahlenther. 155 (1979) 20

Sailer, U.: Veränderung der Dosisverteilung ultraharter Röntgenstrahlung durch Ausstreuung aus Inhomogenitäten. Strahlenther. 156 (1980) 832

Scrimger, J. W.: Backscatter from high atomic number materials in high energy photon beams. Radiol. 124 (1977) 815

Schmelzle, R., N. Schwenzer: Die Überbrückung von Unterkieferdefekten mit Metallimplantaten. Dtsch. Zahnärztl. Z. 32 (1977) 329

Schmelzle, R., N. Schwenzer: Erfahrungen mit der Tübinger Resektionsplatte in der Tumorchirurgie. In: Scheunemann, H., Schmidseder, R. (eds.): Plastische Wiederherstellungschirurgie bei bösartigen Tumoren. Springer, Berlin 1982

Schwartz, H. C., M. Wollin, D. L. Leake, A. R. Kagan: Interface radiation dosimetry in mandibular reconstruction. Arch. Otolaryngol. 105 (1979) 293

Spiers, F. W.: A review of the theoretical and experimental methods of determining radiation dose in bone. Br. J. Radiol 39 (1966) 216

Spiessl, B.: Die Unterkieferresektionsplatte der AO. Ihre Anwendung bei Unterkieferdefekten in der Tumorchirurgie. Unfallheilk. 81 (1978) 389

Stoll, P., R. Wächter, N. Hodapp: Tumorbestrahlung nach Überbrükkungsosteosynthese. Dosismessungen an einem Bestrahlungsphantom. Dtsch. Z. Mund-Kiefer-Gesichtschir. 13 (1989) 165

Tatcher, M., A. Kuten, J. Helman, D. Laufer: Perturbation of cobalt 60 radiation doses by metal objects implanted during oral and maxillofacial surgery. J. Oral Maxillofac. Surg. 42 (1984) 108

Thambi, V., A. K. Murthy, G. Alder, P. K. Kartha: Dose perturbation resulting from gold fillings in patients with head and neck cancers. Int. J. Rad. Oncol. Biol. Phys. 5 (1979) 581

Wall, J. A., E. A. Burke: Gamma dose distributions at and near the interface of different materials. IEEE Trans. Nucl. Sci. 17 (1970) 305

Wambersie, A., J. Dutreix, M. Bernard: Variation de la dose au voisinage de l'interface entre le plexiglas et un métal exposés à des RX de 20 MV. Rad. Biol. Ther. 6 (1965) 237

Dr. Dr. P. Stoll, M.D., D.M.D.
Universitätsklinik für
Zahn-, Mund- und Kieferheilkunde
Abteilung Klinik und Poliklinik für
Mund-, Kiefer- und Gesichtschirurgie
Hugstetterstraße 55
D-7800 Freiburg i. Brsg.
FRG