ORIGINAL ARTICLE

Post-operative radiotherapy of the rhabdomyosarcoma R1H of the rat

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Abstract

Purpose. Post-operative radiotherapy (RT) is routinely applied in the treatment of several human tumours. The aim of the present study was to investigate the value of post-operative RT in a rat model.

Methods. Experiments were performed using the rhabdomyosarcoma R1H of the WAG/Rij rat. Animals were randomized to different treatment schedules: surgery, RT or a combination of both. Tumours were excised at different sizes (0.1–4.5 g) aiming for complete macroscopic resection. RT (60 Gy in 30 daily fractions over 6 weeks) was applied either primarily or to the former tumour site from the third post-operative day. Tumour growth delay, time to recurrence and local tumour control were used as endpoints.

Results. Pre-operative tumour size determined the time and rate of recurrence. The larger the tumour, the shorter the time to relapse and the higher the recurrence rate. The 50% local control rate (LCR50) for surgery was found in tumours with a mass of 0.8 g. For post-operative RT a LCR50 was achieved for tumours with a mass of 1.1 g. For larger tumours (>1.1 g), however, the rate and time course of relapse were similar for both the group receiving RT alone and the group receiving post-operative RT.

Discussion. In this model the tumour mass at excision governs the prognosis. Relatively small R1H tumours may recur despite complete macroscopic resection. With regard to the LCR, the outcome for larger tumours is improved with post-operative RT (60 Gy/6 weeks) than compared with surgery alone. The factor is 1.3. Within a certain range of tumour sizes, combined treatment (surgery + RT) can improve the outcome considerably.

Key words: rhabdomyosarcoma, rat, post-operative radiotherapy.

Introduction

Radical surgical intervention for tumour excision is limited in many cases due to the need to maintain the function of the normal organs concerned. However, one drawback of sparing normal tissue is the enhanced risk of tumour recurrence. Radiotherapy (RT) is a very important additional treatment modality and is a generally accepted approach in curative tumour therapy.1 When applied post-operatively, RT aims to sterilize tumour cells that might possibly, if not definitely, have remained in situ at the time of surgical intervention. Of all the cancer patients who undergo surgery, 30–40% are irradiated post-operatively. A number of questions linked with post-operative RT have yet to be answered, such as at which stage and in which situation will patients profit most.2

It appears obvious that the recurrence rate increases with increasing tumour size. In spite of this the actual tumour stage is a poor prognostic parameter. Moderate treatment radicalism in so-called 'low risk' patients can theoretically invert the risk situation. While aiming for small improvements in higher stage tumours, many therapists consider results in early cancers to be sufficient, despite the fact that they can still be improved. For stage I and II gynaecological cancers, it has been shown that treatment results can be improved by post-operative RT.3,4 The same is true for head and neck tumours.5 Accordingly, even small breast cancers require 50–60 Gy in breast-conserving treatment due to their multi-focal nature.6,7 For sarcomas, it has been demonstrated that the metastatic rate increases considerably after local recurrences.8

Baker et al.9 have performed a study on different experimental tumours. They showed that tumours...
tend to grow better in a post-operative situation—
this was attributed to the expression of specific
growth factors in the operation wound. Thus, theo-
retically, cells remaining post-operatively represent
the risk of a local recurrence, and may further
accelerate the course of the disease unless a valid
adjuvant treatment such as RT is applied. In
addition, it has been shown for breast cancers10 and
sarcomas11 that local recurrences can have a nega-
tive impact on the survival rate. Thus, local control
represents a function of prognosis.12

The rhabdomyosarcoma R1H of the rat has been
found to be suitable for experimental studies of
post-operative RT.13 The present animal study
addressed the question of the role of tumour volume
at surgery, the recurrence rate as a function of
tumour mass at excision and the value of post-
operative adjuvant RT.

Materials and methods
Experiments were performed using the rhab-
domyosarcoma R1H of the WAG/Rij rat (with no
signs of specific immunogenicity).14 Tumour pieces
of about 1 mm³ in size (approx. 10⁶ cells) were
transplanted to the right flank of the animals
under general anaesthesia. Two to three weeks
after implantation the tumours reached treatment
size.13
A total of 131 animals were randomized to differ-
ent treatment schedules consisting of RT (control;
\( n = 8 \)), surgery (\( n = 102 \)) or a combination of both
\( (n = 21) \). One animal was lost due to intercurrent
disease. Control animals were primarily irradiated
when their tumours reached the median size of
0.73 cm³ (range 0.6–1.3 cm³). Tumours were
excised at different sizes (range 0.1–4.5 g). The
extent of excision was limited to the intact pseudo-
capsule aiming for complete macroscopic resec-
tion.13 None of the animals showed signs of residual
tumour masses post-operatively. Local metastatic
spread to lymph nodes was not seen.
Tumours and former tumour sites were irradiated
locally using 200 kVp X-rays under ambient condi-
tions.15 RT consisted of five fractions of 2 Gy/week
over a period of 6 weeks. Thus, total doses of 60 Gy
were applied. In the adjuvant situation, RT was
performed from the third post-operative day.
Following treatment, animals were observed three
times a week. Size-dependent recurrence rates, as
well as specific patterns of treatment response, were
subject to further evaluation. Delay in tumour
growth was defined as the time to regrow to the start
volume \( V_0 \). To evaluate the mass-dependent recur-
rence rates, the range of tumour masses was divided
into 10 equal intervals on a logarithmic scale (Fig.
1). The actual recurrence rates were then calculated
for each intercept and approximated using the max-
imum likelihood method and assuming Poisson

\[
\text{Recurrence rate} (\%) = \frac{\text{Number of recurrences}}{\text{Number of animals at risk}}
\]

\[
\text{Tumour mass at excision (g)}
\]

\[
\begin{align*}
\text{Latency period (d)} & \quad 0.1 \quad 1 \quad 10 \quad 100 \\
\text{Tumour mass (g)} & \quad 0.1 \quad 1 \quad 10
\end{align*}
\]

\[
\text{Fig. 1. Tumour recurrence rate of the rhabdomyosarcoma}
\text{R1H in the rat following surgery as a function of tumour mass}
\text{at excision. The graph also includes animals that received RT,}
\text{as accumulated radiation dose early in the course of treatment}
\text{was unable to prevent temporary recurrence (cf. Fig. 3).}
\]

\[
\text{Fig. 2. There is a correlation between the latency period}
\text{following surgery and the tumour mass. Latency decreases with}
\text{increasing tumour mass (p < 0.001).}
\]

statistics. The non-parametric Spearman’s rank cor-
relation coefficient was used to test for a possible
correlation between latency time and tumour mass
(Fig. 2). Animals that were free of tumour 140 days
after the start of treatment were defined to be
cured.

The experiments were performed according to the
regulations of the veterinarian inspection.

Results
Surgical curability of the rhabdomyosarcoma R1H
of the rat is strongly linked to the tumour mass at
excision. After surgery alone, tumours show a 50%
local control rate (LCR₉₀) at a median mass of
Table 1. Tumour mass as a function of recurrence (R) or cure (C) in tumours receiving 60 Gy post-operatively, also taking into account the clinical observation of temporary recurrences

| Tumour mass at excision (g) | Temporary recurrence | Final outcome |
|-----------------------------|----------------------|---------------|
| 0.65                        | Yes                  | C             |
| 0.7                         | Yes                  | C             |
| 0.7                         | Yes                  | C             |
| 0.7                         | Yes                  | C             |
| 0.7                         | Yes                  | C             |
| 0.8                         | Yes                  | C             |
| 0.8                         | Yes                  | C             |
| 0.9                         | Yes                  | C             |
| 1.0                         | Yes                  | C             |
| 1.1                         | Yes                  | C             |
| 1.1                         | Yes                  | R             |
| 1.5                         | Yes                  | R             |
| 1.5                         | Yes                  | R             |
| 2.5                         | Yes                  | R             |
| 2.5                         | Yes                  | R             |
| 3.0                         | Yes                  | R             |
| 3.8                         | Yes                  | R             |

There is a significant distinction ($\chi^2$-test: $p < 0.0001$) between the mass of tumours that are finally cured (cf. Fig. 3: ○) and those that recur (cf. Fig. 3: ●). Without RT, temporary recurrences would definitely lead to immediate recurrences. This can be avoided ($< 1.1$ g) or postponed ($\geq 1.1$ g) by applying 60 Gy post-operatively.

Discussion

The present study shows that there is a sigmoid relation between tumour mass at resection and recurrence rate for the experimental rhabdomyosarcoma R1H of the rat (Fig. 1). A preformed tumour bed and the activation of growth factors in the operation wound may have an important impact on the patterns of regrowth, which is faster than after tumour transplantation. The growth kinetics appear to be dependent of the tumour mass at excision (Fig. 2).

Both the present study and former data showed a growth delay of 100 days without any local controls following RT alone using 60 Gy. This was independent of the initial tumour size (Fig. 3). Surgery alone achieved a local control rate of only 50% in tumours with a maximal size of 0.8 g. This figure can be as high as 1.1 g when applying 60 Gy post-operatively. Compared to the results for surgery alone, combined treatment significantly ($p < 0.0001$) pushed up the limits of curability by a factor of 1.3. Large tumours ($\geq 1.1$ g range 1.1–3.8 g) recur despite applying 60 Gy after complete macroscopic excision. The latter show a growth delay that is not different from tumours (0.6–1.3 cm$^3$) that have received RT alone (60 Gy). A radiation-induced tumour bed effect can only be seen in the group treated with RT alone. Growth

![Graph](image-url)
delay not only reflects the effect of irradiation on the tumour cells but also on the stroma, which shows a typical influence on the regrowth pattern following irradiation\textsuperscript{16} (cf. Fig. 3).

R1H tumours grow in a pseudo-capsule. Macroscopically, multi-focality is rarely seen in tumours of the size range investigated. Despite complete macroscopical excision the recurrence rate was dependent on the tumour mass. Due to the localization of the recurrences, it does not appear likely that tumour cells are spread in surgery. Moreover, tumour cells outside the pseudo-capsule can cause recurrences in the surgical approach described. Accordingly, tumour cells may be able to cross the capsule and subsequently invade the near vicinity.\textsuperscript{17}

The results suggest that, for the R1H tumour system, the extent of remaining tumour formation is a considerable factor in recurrence. Tumour cells migrate eccentrically from the core of a tumour. During the time the primary tumour has to grow, remote cells begin new clones with growth characteristics identical to those of the primary, thus spilling further satellites. Thus, satellites of smaller tumours consist of single cells. This appears likely when one assumes that the spread of satellites is a continuous process, that may progress parallel to, and with the same growth kinetics as, the original tumour. Accordingly, a satellite tumour may develop out of every remote cell. Tumour mass increases with time, during which, satellites may also grow into a state of relative radioresistance. Tumours of 1.1 g have already had enough time to produce satellites that obey similar radiobiological laws as primary tumours. Previously, it was shown that R1H tumours exceeding 1 mm\textsuperscript{3} cannot be cured by RT alone using 60 Gy.\textsuperscript{16} Hypoxia is held responsible for the relatively high radioresistance in the R1H tumour system.\textsuperscript{18} Hence, hypoxia might also be important in the satellites of primary tumours larger than 1.1 g.

As the satellites are not yet macroscopically detectable during surgery, they may remain in situ. There is no obligatory connection to supplying blood vessels. Accordingly, the actual tumour and its satellites are in a competitive situation. By excising the main tumour, all the nutritive supply of the tumour bed becomes concentrated in the remaining smaller cell formations. This may, in addition to operation-induced growth factors,\textsuperscript{9} serve as an explanation for the observation of faster tumour regrowth following surgery rather than after transplantation. The fact that 80\% of all recurring tumours occurred within 14 days supports this theory.

The results presented are considered to be of clinical interest. Particularly in early and limited tumours, post-operative RT can sterilize these remaining cells and thus improve outcome. This has been shown for gynaecological cancers\textsuperscript{34,19-21} breast cancers\textsuperscript{6,7} and head and neck tumours,\textsuperscript{2,3} as well as for sarcomas.\textsuperscript{1,12}

Similar to clinical tumours eccentric cell migration plays an important role in experimental tumours. Thus, the migration phenomenon has to be taken into consideration when defining the target volume for RT. Concentric, solid cell formations require larger doses than eccentric single cells, and larger tumours demand larger surgical safety margins. This is despite the need for smaller photon doses at the periphery. On the one hand, penumbra irradiation has a positive impact on the outcome. On the other hand, new and more precise irradiation techniques such as 3-D planned multi-leaf collimator techniques and proton irradiation reduce the size of the penumbra volume, thus increasing the risk of leaving persisting tumour cells untreated.

The experimental data provided show that even small tumours may have an unexpected high recurrence rate following surgery alone, especially when the extent of surgical treatment is limited for several reasons. The outcome can be improved significantly by consequent application of post-operative RT.

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