CLINICAL EXPERIENCE WITH THE 160 MeV PROTON BEAM AND SOME IMPLICATIONS FOR DESIGNERS

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ABSTRACT

The 160 MeV synchrocyclotron at Harvard University has been operated as a medical facility since 1968. Well over 1000 patients have been treated here, and the present load is about 150 patients per year. A number of different disorders have been treated, among them benign tumors of the pituitary gland, blood vessel malformations within the brain, malignant melanomas within the eye and cancer of the prostate. Enough patients with each of these disorders have been treated to justify estimates of the technical requirements, the patient load, and the cost limitations for an accelerator installation for the treatment of each disorder. Increasing the technical capabilities for a proposed installation will generally increase the cost as well as increasing the variety of disorders that can be treated. The designer should try to balance increased cost against expected benefit.

I. Introduction

The Harvard Cyclotron Laboratory (HCL) has been involved for a number of years in the development of novel methods of treatment for several diseases in man. These applications of the proton beam have been developed in collaboration with the Massachusetts General Hospital, the Mass. Eye and Ear Infirmary and the Retina Foundation. Although other promising applications are being explored, satisfactory results have been obtained with the following classes of treatment: Class 1: Single-fraction definitive treatment of benign tumors of the pituitary and of other benign intracranial lesions[1,2,3]. Class 2: High-dose fractionated treatment of malignant melanomas within the eye[4,5]. Class 3: Conventionally fractionated boost treatment of prostate cancer using a perineal field[5,6]. For each of these classes of treatment the physical properties of a proton beam (or beam of heavier ions) appear to be essential to the demonstrated success of treatment.

The incidence of diseases corresponding to Class 1 and Class 2 is not high, and in Class 3, perhaps only 5% of diagnosed prostate cancers will meet the criteria for proton boost treatment. Thus these methods of treatment developed at HCL, although successful, offer increased benefit to only a very small fraction of the population. Nevertheless we find that the case load at HCL is sufficient to require nearly 40 hours per week of accelerator operation.

From the economic point of view it is remarkable that for ten years all costs of Class 1 treatments have been paid by the patients or their health-insurance plans, the present costs of Class 2 treatments are at a level where similar arrangements are being considered, and it seems entirely feasible to reach an unsubsidized cost recovery basis for Class 3 treatments in the near future. The only "hidden subsidies" in this financial picture are the capital costs of the accelerator and building, constructed in the period 1948-50 and altered substantially in 1963 and 1977. The cost of the accelerator has been written off entirely; building amortization is at the low rate of about 2% per year.

Some of the information concerning the HCL operation has implications for the general problem of designing an accelerator and treatment facilities specifically for medical use. In particular we believe that relatively modest installations serving a limited population will have a useful role, although our data are certainly not conclusive.

2. Patterns of Patient Referrals

To achieve a reasonable case load when cases suited to such specialized treatment are relatively rare, it is necessary to develop a good referral network. Figure 1 indicates that the case load of Class 1 patients has grown steadily but slowly over the years, suggesting the existence of a well-established and stable referral network.

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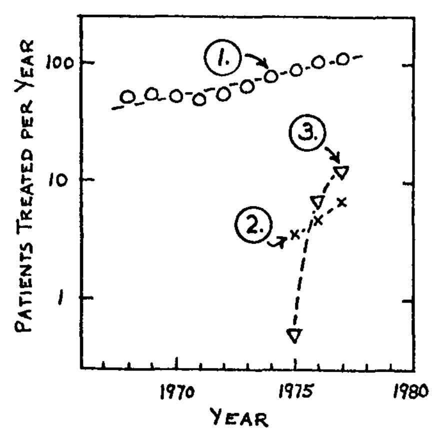

Figure 1 Patients treated at HCL per year according to class of treatment. Class 1 is the single-dose definitive treatment of benign pituitary and intracranial lesions. Class 2 is the high-dose fractionated treatment of malignant melanoma in the eye. Class 3 is the conventionally fractionated boost treatment of cancer of the prostate. The points are two-year moving averages.

* * *

We have examined the provenance of patients treated since 1 January 1975 in order to answer two related questions: How important are different parts of the world in supplying patients to HCL? How effective is HCL in providing treatment to those who require it in different parts of the word? We have counted the number of patients from each state or province in the U.S.A. and Canada as well as from other countries, and have grouped these counts into larger geographic territories where appropriate to achieve reasonable statistics. Figure 2 presents the data in terms of a cumulative percentage of the patients versus the distance travelled to receive treatment. It is seen that territories 400 miles and more away contribute almost as many patients as our own state of Massachusetts.

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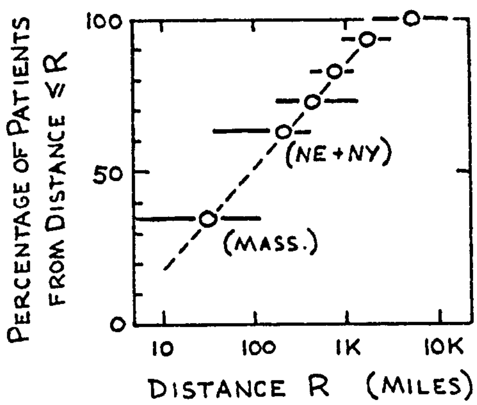

Figure 2 Distance travelled by patients to receive treatment. 35% of total patients came from the state of Massachusetts (first point), 62% from the territory made up of New England plus New York State (second point). Population weighted mean distances have been estimated, the bars indicating range of distances for each territory.

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To examine our effectiveness in delivering this type of health care we have computed a referrals rate for each of these territories: that is, the number of patients referred for treatment per year per million inhabitants within that territory. The result is shown in Figure 3.

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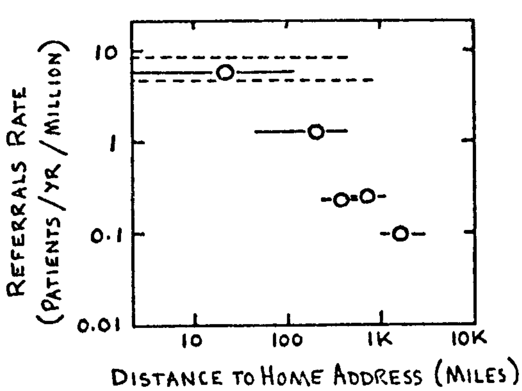

Figure 3 Rate of patient referrals for Class 1 treatment versus distance. For each geographic territory the number of patients per year per million population within that territory has been computed. The dotted lines represent two estimates of the total incidence rates of the diseases appropriate for class 1 treatment.

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To provide some point of reference for the scale of referrals rate we have estimated an upper limit based on the rates of incidence of the appropriate diseases as quoted in the literature[7,8,9]. There are some questions of interpretation and some disagreement among authors, so we have shown in Figure 3 two dotted lines representing high and low estimates of total incidence. From this it appears that nearly all new cases originating in Massachusetts are being referred to our group for treatment. However, the referrals rate is already a factor of 5 or 6 less for the territory made up of our next neighboring states, typically 200 miles distant, and continues downward at still greater distances. There has been essentially no change in this pattern within the time period studied except for a substantial increase in the referrals rate outside the U.S.A. and Canada. The radius at which the rate drops to half its central value is around 150 miles which would include a total population of around 20 million.

If we accept these observations to be representative of the pattern of referrals in other parts of the U.S.A. and Canada and to apply to other highly specialized treatments similar to those considered here, it appears that the pattern of patient referrals may limit the size of population which can be effectively served by a specialized treatment facility to something like 20 million. To provide effective service to a larger population requires multiple centers, perhaps as many as ten for the U.S.A. and Canada.

3. Cost Considerations

In this section we assume a treatment center providing the specialized treatments described above to a total population of 20 million. To estimate the case load at such a center we have used published incidence rates for the appropriate diseases and multiplied by a factor estimating the fraction of cases suitable for proton beam treatment.

Table 1

Estimated Annual Case Load
at a Specialized Treatment Center

Class	Incidence	Ref.	% Suitable	Case Load
1	7/10	7,8,9	90	126
2	5	10,11	60	60
3	251	12	5	250

In order to arrive at an estimate of possible revenue we have chosen charges for the irradiation service which appear reasonable compared to present charges at HCL and elsewhere. The charge of $800.00 for a Class 1 irradiation is nearly double the present charge at HCL, but still represents only 1/3 of the total hospital charges for the entire procedure[13] and may also be compared with the typical operating room charge of $765.00 for a craniotomy in 1977[14]. The charge of $2400.00 for a complete Class 2 irradiation is 1.4 times the present charge at HCL. This figure represents about 2/3 of the the estimated total hospital charges for the entire procedure, and may be compared to a hospital charge of $800.00 to $1100.00 for surgical removal of the eye containing the tumor. The cost of a prosthesis should also be considered. The charge of $75.00 per fraction for Class 3 treatments is believed to be comparable to the technical charges for treatment with a betatron. Applying these figures to the estimated case load, we have calculated the revenue for such a treatment center.

Table 2

Estimated Annual Revenue
from a Specialized Treatment Center

Class	Case Load	Charge	Fractions	Charge/ Fraction	Annual Revenue
1	126	$ 800	1	$800	$100,800
2	60	2400	5	480	144,000
3	250	900	12	75	225,000
				Total	$469,800

Against this revenue must be charged the operating expenses of the installation. We have simply used the 1978-79 budget for HCL, which is $200,000 for somewhat over 40 hours per week operation. Using estimates of hours per fraction for each class of treatment, we estimate that the case load derived in Table 1 will require an average of 37 hours per week of operation. We can thus make an estimate of the economically allowable capital cost of the specialized treatment facility.

Table 3

Allowable Capital Cost
of Specialized Treatment Center

Annual Revenue	$469,800
Operating Expense	200,000
Balance available for amortization	269,800
Capital Cost	
5 year straight line	1.35 million
10 year straight line	2.70 million

To indicate that it is an encouraging figure, we refer to a study by Burleigh, Clark and Flood[15] estimating a total cost of $914,000 (1973) for a bare-bones 150 MeV proton machine with vault, but without treatment rooms. Escalating this estimate at 7% per year yields a cost of $1.28 million (1978). Since a useful life of more than 10 years has been shown at HCL, one might expect to build a complete specialized treatment center at an economical cost.

Conclusions

The Harvard Cyclotron Laboratory has operated for more than ten years as a specialized medical treatment center, demonstrating the financial viability of such operation. Furthermore, the modest output of our machine, 5×10^{10} protons/sec. at 160 MeV, has proved to be well suited to our medical treatments. The geographic pattern of patient referrals to HCL indicates that such a center is effective in delivering its specialized services only to a limited population of perhaps 20 million. To extend these services effectively to more people will require the construction of additional centers. Using data from the HCL experience and other sources, we have estimated case loads, revenues and operating expenses for such a center, concluding that a construction cost of several million dollars can be justified. A number of relatively small centers designed with these points in mind could make an effective contribution to the delivery of the best in health care.

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** DISCUSSION **

G. HEYMANN: What are the other treatment options available compared to that discussed in your talk?

A. KOEHLER: For the intracranial lesions, surgery is an alternative but carries a risk of operative mortality of perhaps 2% and much longer convalescence, often 2 weeks in the hospital. For eye tumors the accepted alternative treatment is removal of the eye. For prostate tumor boost therapy, no other method now in use permits carrying the tumor volume to such high dose without unacceptable side effects.

G. HEYMANN: How do costs compare?

A. KOEHLER: The total hospital bill for patients receiving comparable intracranial surgery is 1.5 to 2 times the total bill for patients receiving proton beam treatment. The total hospital bill for eye patients receiving proton treatment will be about 2 times the bill for removal of the eye. The technical cost per fraction of prostate boost treatment is comparable to the cost on a betatron or high-energy therapy linac.

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