THE USE OF ELECTRON CONFORMAL THERAPY
IN THE CLINICAL SETTING

A Research Project Report Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Medical Dosimetry

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We recommend acceptance of this project report in partial fulfillment of the candidate's requirements for the degree of Master of Science in Medical Dosimetry

The candidate has met all of the project completion requirements.

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Abstract

The purpose of this project is to demonstrate that Bolus Electron Conformal Therapy (BolusECT®) is the ideal treatment option for superficial lesions that are difficult to treat due to irregular patient contours. History has shown various materials have been used as bolus material such as water, tinfoil, paraffin wax, etc. BolusECT® uses a custom milled bolus to smooth out patient surface irregularities. Compared to conventional bolus BolusECT® conforms more closely to the patient surface and reduces air gaps which lead to the patient being underdosed. The custom milled material used in BolusECT® allows the clinician to treat fields in a single enface field that were previously treated with multiple matching fields, reducing the risk overlap and overdosing the area. The user is able to control the thickness of BolusECT® in order to sculpt the electron beam precisely to the tumor volume while sparing underlying tissues. This research demonstrates that BolusECT® provide clinicians with the knowledge that tumor volumes under irregular surfaces are being more accurately treated.
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Chapter I: Introduction

High-energy electrons have been used to treat cancer since the 1950’s\(^1\). The range of electron energy that is clinically useful is 6 to 20 million electron volts (MeV). In this range, electrons have a sharp dose drop off that can be used to treat tumors, specifically those less than 5 centimeters (cm) deep. Electron therapy offers the ability to treat superficial tumors with minimal dose to the underlying tissue. Electron therapy is used in treatment of skin and lip cancers, tumors of the chest wall, head and neck cancers and to administer additional radiation at the end of the treatment course to boost nodal and lumpectomy cavities to a tumorcidal dose. Electron therapy is useful in radiation therapy due to shape of the depth dose curve, characterized by uniform dose that rapidly decreases as depth increases.\(^1\)

The depth dose curve of electrons begins at approximately 85% of the maximum dose and builds up to 100% dose within the first few centimeters of treatment. The dose then rapidly decreases. Due to the build up, the surface tissue to the area of maximum dose (dmax) is often undertreated. The electron dose curve has a unique shape in that it has a lateral bulge. This bulge decreases as electron energy increases. The electron dose curve is also affected by slopes of the patient surface and by missing tissue. These issues can be solved by the use of bolus.

In radiation therapy, bolus is used to mimic tissue. The same material used in photon therapy has traditionally been used in electron therapy. Through the years many materials have been used as bolus material: Vaseline gauze, wet gauze, water, tinfoil, paraffin wax, plastic, Lucite, super flab and polystyrene. The density of the bolus material needs to be tissue equivalent. Bolus material should closely conform to surface irregularities, the physical attributes be unaffected by radiation, durable, non-toxic and cost efficient.\(^2\) Bolus has three applications in electron beam therapy: 1) to increase the dose to the patient surface, 2) to compensate for irregularities of the patient’s surface and internal heterogeneities within the area to be treated,
and 3) to reduce electron beam penetration within the patient. Traditionally electron fields cover the planning tumor volume (PTV) geometrically but the dose distribution may not be adequate. This typically requires the use of matched adjacent electron fields. Using adjacent fields may lead to areas of under dose or overdose at the junction of the fields. Areas of overdose may be small and clinically insignificant, while areas of under dose may be more significant if located within the PTV.

Bolus Electron Conformal Therapy (ECT) is a way to treat cancer using electron radiotherapy with custom compensators. By employing a single electron field with a custom milled compensator (Figure 1), BolusECT allows the user to conform the 90% isodose line to the distal surface of the PTV, while delivering minimal dose to adjacent critical structures. Using BolusECT allows for shorter treatment times as only one treatment beam is required. Where treatment with photons may be a problem, BolusECT can create favorable dose distributions for tumors of the chest wall, head and neck region, extremities and other treatment sites. BolusECT may be used where the tumor volume is close to the patient surface. While BolusECT is not a new procedure, it is one that is not currently used to its fullest potential in the treatment of superficial tumors nationwide. However, the University of Texas M.D. Anderson Cancer Center has utilized BolusECT since the early 1990’s.

Statement of the Problem

Electron treatment of lesions has been studied for many years. In addition the use of bolus has also been well documented. The advent of BolusECT has added a new dimension to the treatment of superficial lesions. This approach offers a new tool for the radiation oncologist. BolusECT allows the user to conform the electron dose to a specific area. BolusECT permits single field treatment areas that previously required multiple matching fields. This single
electron beam uses a variable thickness bolus compensator. BolusECT® aids in the creation of optimal depth dose curves in areas that were previously difficult to treat. This treatment modality has not been as widely studied as conventional electron bolus therapy. As a result this technique is not widely used in radiation therapy. According to Ken Cashon, MS, Director of Clinical Services at .decimal, currently only 85 clinics across the United States are using BolusECT®.

**Purpose of the Study**

The purpose of this study is to demonstrate the use of BolusECT® in radiation oncology. The advantages, clinical applications and treatment planning process of BolusECT® will be discussed. Data will be collected through literature review and a retrospective study of patients that were treated with BolusECT® at Northwestern Lake Forest Hospital.

**Assumptions of the Study**

This study will demonstrate that BolusECT® is a useful method of treating superficial tumors and that BolusECT® is able to treat tumors when conventional electron therapy with bolus is not feasible. BolusECT® allows for the treatment of tumors while sparing underlying and surrounding normal tissue and provides more dose conformity to the PTV. BolusECT® is able to produce conformal dose for very complex, superficial tumors and patient surfaces. This is done by making the patient surface anatomy as comparable to a water phantom as possible. Thus resulting in a more homogenous dose distribution.

**Definitions**

*Attenuation*- removal of electrons from a radiation beam either by scatter or by absorption as the beam travels through a medium.

*Algorithm*- a set of rules for solving a problem in a finite number of steps.
Bolus- material used in radiation therapy that interacts with the radiation beam as a mimic to normal tissue when placed directly on the patients skin.

BolusECT®- use of a single electron beam with a variable thickness compensator.

Compensator- “beam modifier that changes radiation output relative to loss of attenuation over changing patient contour”

Dose maximum (Dmax)- the depth of maximum build up where 100% of the dose is deposited.

Electron- negatively charged subatomic particle used for external beam treatment.

Electron density- the number of electrons per cubic centimeter.

Immobilization- use of devices to ensure the patient does not move during the treatment.

Immobilization device- device that ensures that the patient does not move during the treatment, i.e. masks, Vac-Loks™, bite blocks, wing boards etc.

Isodose curve- plotted percentage depth dose at various points along the central axis of the radiation beam.

Simulation- positioning of patient and placement of fields.

Treatment verification- final check in the treatment room that the planned beams cover the PTV.

Verification simulation- final simulation check that the beam covers the PTV and does not irradiate normal structures.

Virtual simulation- shaping of fields to conform to the PTV completed on the treatment planning system (TPS). The patient is not present.

Limitations of the Study
This study is limited by the lack of literature devoted to BolusECT®. The compensator manufacturer’s website has information regarding BolusECT® but it does not provide an exhaustive review. As a result of limited literature available, BolusECT® is not being widely used which diminishes the database available for this literature review.

Methodology

This study will be a retrospective review of the literature available for BolusECT® as well as patients treated at Northwestern Lake Forest Hospital with BolusECT®. The use of traditional bolus used in electron therapy as compared to BolusECT® will be discussed. Scientific literature regarding electron therapy and BolusECT® will be analyzed. Case studies in the literature as well as cases at Northwestern Lake Forest Hospital will be reviewed for this study. The review of case studies will demonstrate that BolusECT® is a viable treatment option when treating patients with irregular surfaces as well as treating areas that previously would not be amenable to treatment with electrons.

A review of the benefits and challenges in using BolusECT® will be discussed in this paper. The clinical applications of using BolusECT® will also be presented. Finally the treatment planning processes for BolusECT® compared to non-bolus plans at Northwestern Lake Forest Hospital will be discussed.
Chapter II: Literature Review

Introduction

Electron beams are used to treat superficial lesions due to their unique characteristic depth dose curves and high surface doses. The higher energy electron dose curve exhibits a wide plateau followed by rapid dose fall off. Treatment with electron beams can be complex in nature. The electron beam is sensitive to changes in tissue heterogeneity, the patient contour and in the shape and size of the electron beam. As the electron beam passes through tissue it has a greater potential to interact with an atom than a photon due to its negative charge. As the electron beam interacts with matter it expands below the surface due to scattering of the electrons. This scattering can be controlled through the use of bolus. This is done by providing extra scattering or degradation of the electron beam.

Bolus is defined as “tissue equivalent material, that is usually placed on the patient surface to increase the skin dose and/or even out irregular surfaces” The bolus material mimics the tissue interaction with the photon or electron beam. Bolus is used in electron therapy primarily for three reasons: 1) to flatten out an irregular surface, 2) to reduce the penetration of electrons in specific field regions, and 3) to increase the surface dose. The material chosen for bolus should be of the equivalent stopping power and scattering power as normal tissue. The thickness of the bolus is designed so that when added to the patients surface the distal PTV surface is equal to the therapeutic dose (the 90% isoline) of the chosen electron energy. To understand the use of bolus in electron therapy one must first understand the characteristics of the electron beam.

Characteristics of electron beams

As stated previously the electron beam has a unique depth dose curve with a region of uniform dose followed by a rapid fall of dose. This treatment offers advantages over photons. As
the energy of the electron beam increases, this advantage decreases. This makes the electron beam especially useful for the treatment of superficial tumors while sparing structures at greater depths.\textsuperscript{10} Electron beams lose energy at a rate of approximately 2 MeV per centimeter of water or tissue.\textsuperscript{1} The therapeutic range of electrons is considered within the volume of the 90\% isodose line because the depth dose decreases rapidly thereafter. Unlike photons the percent surface dose for electrons increases with energy. At lower energies the electron beam scatters more.\textsuperscript{1} When a beam of electrons passes through a medium, the electrons suffer multiple scattering due to Coulomb force interactions between the incident electrons and predominantly the nuclei of the medium.\textsuperscript{1} As the electron beam traverses the patient, its mean energy decreases and its angular spread increases.

**Oblique Surfaces and Beam Divergence**

The slope of the patient’s surface may also change the depth dose curve. Electron beams that are oblique to the patient surface demonstrate an increase of dose at \(d_{\text{max}}\), a shift in \(d_{\text{max}}\) towards the patient’s surface, a shifting of the 80\% isodose line towards the surface and a shift of the 10\% isodose line away from the surface.\textsuperscript{11} The tissue closer to the beam receives more scatter while the tissue away from the beam receives less scatter. As the electron beam diverges the air gap between the end of the electron cone and the surface of the patient increases with obliquity. This causes a decrease in the depth dose.

Khan et al.\textsuperscript{10} measured electron beams at different angles of obliquity on a phantom. They noted a failure to show a universal obliquity curve. They also noted an inconsistent behavior in the curves near the surface. This behavior was especially noticeable when the beam was 30\degree to 45\degree incident upon the surface. This was due to the varying degree in scatter contribution. A table of obliquity factors was developed to compensate for the changes in the
depth dose. These tables are used along with correction for the inverse square law to correct for the oblique incident of the beam along the patients surface. This will aid in compensation for air gaps, beam obliquity and sloping contours. Manual calculations can be performed by using these tables.

**Bolus Effect**

Gunhan et al.\(^3\) demonstrated that the isodose curves shifted towards the surface as the thickness of the bolus was increased. This was done by placing thermoluminescent dosimeters (TLD’s) on a Rando phantom. The TLD’s were placed at the center of the electron field as well as 5 cm off center toward the edges of the field on either side. Measurements were made using electron energies of 6, 7.5, 9 and 15 MeV with and without bolus. They also showed that the therapeutic range of the electron beam decreases with the thickness of the bolus material used. Their study also showed that the surface dose increased with both increasing electron energy and bolus thickness especially at lower electron energies.

The effect of the bolus is more obvious at lower energies. The reason for this being that the surface dose is lower and is shallower with lower electron energy beams. When the bolus is placed on the skin, the d\(_{\text{max}}\) shifts toward the surface resulting in a higher surface dose. In higher electron energies where the d\(_{\text{max}}\) range is wider, the bolus did not affect the surface dose as much. The study concluded that when using low energy electron beams, the use of bolus is of benefit in cases where the dose to the surface needs to be increased. In the case of high energy electron beams, the use of bolus is beneficial in reducing dose to healthy tissue underlying the treatment area.\(^3\)

**Dose Heterogeneities**
Dose heterogeneities can occur in areas that have an irregular surface such as the external ear and auditory canal. Morrison et al.\textsuperscript{12} demonstrated that when treating the external ear, the surfaces of the external auditory canal received excessive dose. It was shown that electrons scattering from tissue into air cavities are not replaced by electron scattering from the air into the surrounding tissue. The result was increased dose to tissue around and deep into the auditory canal. By using bolus as a missing tissue compensator the maximum point dose of 173\% of the given dose was reduced to a maximum point dose of 125\% of the given dose. The bolus material that was chosen for this study was water. Two computerized tomography (CT) scans were performed. One was performed with the ear canal filled with warm water, which acted as bolus. The second was performed without water. Treatment plans were performed on both sets of scans using 15 MeV electrons. The plan without bolus demonstrated dose heterogeneity occurring in the ear canal. The plan with the water bolus showed a more homogenous dose distribution. This plan with bolus was further improved when the external ear was flattened. By flattening the external ear the scatter that was caused by the helix and tragus was reduced.

\textbf{Materials Used As Bolus}

Through the years many materials have been used and continue to be used as bolus. As mentioned previously, water has been proven to be an excellent bolus material for treating areas such as the ear. The key component when choosing a bolus material is that the material should closely conform to the patient’s surface. This includes conforming to any surface irregularities including those caused by surgical defects. As previously mentioned the physical attributes of the bolus material needs to be unaffected by high levels of radiation, non-toxic, durable and cost effective.\textsuperscript{2}
Arancini and Brackenridge\textsuperscript{4} discussed a method of using tin-foil when treating the nose with electrons. The anatomical shapes as well as the inhomogeneity of the treatment volume complicate radiation therapy to the nose. When treating the nose with electrons, a single field may cover the PTV geometrically but the dose distribution is often found to be inadequate. The use of matched fields may lead to under dose or overdose at the junction of the fields. By creating a tin-foil bolus that extends 1 cm past the PTV they were able to achieve 90\% dose coverage to the PTV; however use of the tin-foil bolus resulted in acute skin reactions both externally and internally. Patients treated with tin-foil bolus experienced erythema and dry desquamation. In the latter stages of treatment the skin reaction progressed to moist desquamation. The authors discovered that the acute skin reaction tended to be more severe when the tin-foil bolus was used as compared to the skin reaction when a tissue-equivalent bolus was used.\textsuperscript{4}

A study done by Humphries et al.\textsuperscript{13} compared the use of Super Stuff\textsuperscript{®} to paraffin wax bolus material. The making of a paraffin wax bolus is a time consuming process. First, a plaster mold must be made of the treatment area, then a box cast is built around the mold to help retain its shape. Lastly, molten wax is then poured into the mold and allowed to harden overnight. In contrast, the process of making a Super Stuff\textsuperscript{®} bolus can be performed in minutes. An Aquaplast\textsuperscript{®} mask is made of the area to be treated. Water is then added to the bag of Super Stuff\textsuperscript{®} and mixed. Some additional Aquaplast\textsuperscript{®} is used to hold the Super Stuff\textsuperscript{®} in shape. Humphries et al.\textsuperscript{11} then performed measurements under the paraffin wax bolus and the Super Stuff\textsuperscript{®} bolus using TLD’s. They discovered that the readings of the TLD’s were comparable. This demonstrated that Super Stuff\textsuperscript{®} had approximately the same dosimetric effect as the paraffin
wax bolus. The TLD measurements verified that using the faster and easier Super Stuff\textsuperscript{®} achieved comparable results.\textsuperscript{13}

Dubois et al.\textsuperscript{2} compared four different materials in their study to find a moldable tissue equivalent bolus. The study included a comparison of Reprosil\textsuperscript{®}, an addition silicone impression material, Neo-Sil\textsuperscript{®}, a condensation silicone impression material, Reprogum\textsuperscript{®} a polyether impression material and Polyflex\textsuperscript{®}, a hydrocolloid impression material. All four materials were exposed to 9 MeV electrons and compared to readings taken in solid water. After the first set of readings Reprosil\textsuperscript{®} and Neo-Sil\textsuperscript{®} were found to show -51.7\% and -12.3\% deviation respectively in the readings as compared to the solid water. These two were therefore eliminated as possible tissue equivalent materials. The Polyflex\textsuperscript{®} and Reprogum\textsuperscript{®} produced readings of -5.3\% and -1.9\% deviations. Further readings at 6 and 15 MeV showed comparable results. Both materials showed excellent tissue equivalence and moldability. However Reprogum\textsuperscript{®} is no longer available in the United States making Polyflex\textsuperscript{®} the only choice available.\textsuperscript{2}

A study completed by Jones\textsuperscript{14}, demonstrated the use of emergency first-aid air splints as a bolus material for the treatment of Kaposi’s sarcoma. Traditionally submerging the extremity directly into a water bath was used to treat Kaposi’s sarcoma. This technique limited the treatment area to the lower leg due to the difficulty of placing the limb in a water bath. By filling an air splint with water the user was able to treat more of the involved extremity. A CT was performed to demonstrate the conformity of the water filled air splint to the affected extremity. The water filled air cast allowed for homogeneous dose to the extremity as a result of the bolus closely conforming to the patients extremity.\textsuperscript{14} The bolus conformed to the patients leg on the inside while retaining the same thickness on the outside thus allowing for a uniform dose distribution.
Cederbaum et al.\textsuperscript{15} performed a study utilizing Tantalum (Ta) wire mesh to increase the dose to the chest wall when using high energy electrons. An open field without the wire mesh in combination with a Ta wires mesh to “spoil” the electron beam was utilized. This allowed for modulation of the skin dose. This increased the dose at the skin from 81\% to 99\% for a 6 MeV beam and from 86\% to 100\% for a 9 MeV beam. The use of Ta wire mesh in conjunction with an open field allowed for a flattening out of the percent depth dose (PDD) at the surface while maintaining a sharp fall off.\textsuperscript{15}

Another study using the dental mold, Jeltrate\textsuperscript{®} Plus was done by Babic et al.\textsuperscript{16} Various concentrations of Jeltrate\textsuperscript{®} Plus powder mixed with water were used. The combination of 2:3 Jeltrate\textsuperscript{®} Plus powder to water proved to be the most durable of the combinations tried. At this point percent depth ionization measurements were performed using 6, 12 and 20 MeV electrons. For 6 MeV the Jeltrate\textsuperscript{®} Plus bolus PDD curves proved to be within 1 millimeter (mm) of that of solid water. For 12 MeV the PDD curves were within 0.5 mm the solid water measurements. The 20 MeV curves were identical under Jeltrate\textsuperscript{®} Plus bolus as that of plastic water. These results showed that Jeltrate\textsuperscript{®} Plus bolus is an effective tissue equivalent material.\textsuperscript{16}

**Custom Bolus Electron Case Studies**

Several studies have used customized bolus to modulate the electron beam. One study at the University of Louisville by Amin-Zimmerman et al.\textsuperscript{17} studied 273 patients between 1985 and 1998. All of the patients in the study underwent post-mastectomy radiation at the University of Louisville. In each case, the patient was treated to the chest wall with a 6 MeV electron beam and a 0.5 cm tissue equivalent bolus normalized to the 90\% isodose line. The results of this study presented favorable results of treating the chest wall with low energy electrons. Twenty-one patients developed pulmonary fibrosis. This fibrosis was in the supraclavicular area, which was
treated with a single anterior 6 MV photon beam. The areas treated with the electron beam did not demonstrate fibrosis. Twenty patients (7.3%) experienced locoregional failure, while fourteen patients (5.1%) developed chest wall recurrence. The technique of treating the chest wall with low energy electrons and bolus demonstrated low levels of radiation toxicity and having excellent control of local disease.\textsuperscript{17}

Low et al.\textsuperscript{18} described the fabrication process to create a custom electron bolus to treat the paraspinal muscles. The patient treated was a 17-year old woman with mesenchymal chondrosarcoma of the right paraspinal muscle at the level of T8-T12. The patient completed three cycles of chemotherapy with a partial response. The tumor measured 11 x 9.5 cm. The treatment field measured 23 x14 cm. The target volume overlaid part of both lungs, the right kidney and the spinal cord. Because of the patients young age the authors wanted to spare as much of the normal tissue as possible. The target dose was 50 Gy in 25 fractions normalized to the 90\% isodose line. The plan was for the patient to receive 40 Gy with 17 MeV electrons in combination with 10 Gy treated with 6 MV photons. The electron dose was to be given four days of the week and the photon dose on the fifth day of each week. The patient was treated in the prone position with both fields treated from a posterior direction. The patient underwent a treatment planning CT (TPCT) scan with contrast filled catheters placed on the patients skin to outline the nominal treatment field. The CT scan was done with 1 cm slices that encompassed 5 cm superior and inferior to the nominal treatment field. The TPCT was then exported to an in-house treatment planning system (TPS) to design the bolus. The bolus was designed so that the 90\% isodose line covered the distal edge of the tumor. The bolus was then fabricated on the TPS computer driven milling machine using resin-impregnated wax. The bolus had a physical density of 0.92 grams (g) cm\textsuperscript{-3}. The bolus was placed on the patient’s surface and an additional TPCT
was performed. The bolus was placed perpendicular to the electron beam and there was minimal air-gap with the patient surface. The second TPCT was exported to the TPS to evaluate the design. A new treatment plan was done to verify that there was adequate coverage of the PTV by the 90% isodose line. The dose volume histogram (DVH) from the bolus plan was compared to the original non-bolus plan to assess the bolus plan dose contribution to the organs at risk (OAR). Comparison of the two plans demonstrated that 55% of the spinal cord received a dose 45 Gy or more in the plan with no bolus, while the bolus plan demonstrated less than 5% of the spinal cord received 45 Gy or more. The percent of the right lung dose receiving 20 Gy was 40% for the non-bolus plan compared to 20% for the bolus plan. The right kidney also demonstrated a significant improvement for the bolus plan. Five percent of the right kidney received more than 26 Gy, while 40% of the right kidney received over 26 Gy in the non-bolus plan. The bolus plan was a better plan overall in that it demonstrated significant reductions to the OAR while providing coverage to the PTV.\textsuperscript{18}

A study at the University of Texas, M.D. Anderson Cancer Center by Perkins et al.\textsuperscript{19} demonstrated the benefit of custom bolus in the use of post mastectomy irradiation. Patients that had pectus excavatum deformity could be treated with use of conformal bolus by adjusting the thickness across the bolus. The researchers were able to design plans with custom bolus that allowed the 90% isodose line to cover the PTV while sparing the OAR. Another benefit was the ability to treat the entire chest wall, internal mammary chain and supraclavicular nodes (if needed) in a single anterior electron field. By using this technique there were no match lines as there would be if conventional fields were used. This reduced the chance of hot and or cold spots at the junction areas.\textsuperscript{19}
Dr. Hogstrom was part of the team that initially developed the concept of variable tissue compensators to be used with electrons at the University of Texas MD Anderson Cancer Center. Dr. Hogstrom’s team originally used an in-house milling system to manufacture the bolus. Through the years, with the use of CT scans, the bolus has been made more accurately. Dr. Hogstrom worked with decimal to achieve an optimal milling process for the BolusECT®.  

One of the new concepts that Dr. Hogstrom described was the use of BolusECT® in conjunction with intensity modulated radiation therapy (IMRT). Historically the patient would receive electron conformal therapy four days a week and on the fifth day would be treated with a conventional photon field. By treating the patient four days with a BolusECT® field and the fifth with an IMRT field the dose volume histogram (DVH) would be able to “cleaned up” as Dr. Hogstrom described it. This means that the user would have more control over the DVH by combining the two modalities. This may also potentially decrease the side effects that patients may have if treated with BolusECT® alone.

As stated previously electron beams are used to treat superficial lesions due to their unique characteristic depth dose curves and high surface doses. The electron beam is sensitive to changes in tissue heterogeneity, the patient contour and in the shape and size of the electron beam. Using a conformal bolus such as BolusECT® allows the medical dosimetrist to shape the isodose distribution to the treatment area. It also allows for underlying tissues to be spared dose. A single electron beam may now be used in areas where multiple beams were used previously. BolusECT® reduces the need for matching fields. As a result under dosing or overdosing of tissue is greatly reduced.
Chapter III: Methodology

Treatment of lesions with electrons has been studied for many years. The addition of bolus has been well documented. The advent of BolusECT\(^\circledR\) has added a new dimension to the treatment of superficial lesions. This approach offers a new tool to the radiation oncologist. BolusECT\(^\circledR\) allows the user to conform the electron dose to a specific area. A single field with the use of BolusECT\(^\circledR\) can now treat areas that were previously treated with multiple matching fields. By using a variable thickness compensator, BolusECT\(^\circledR\) uses a single electron beam for treatment delivery to the affected area. Areas that were previously considered problematic due to irregular or sloping surfaces are no longer such an issue using BolusECT\(^\circledR\). BolusECT\(^\circledR\) aids in the creation of optimal depth dose curves by providing an even surface.\(^7\) This modality of treatment has not been widely studied as conventional electron therapy or the use of bolus in electron therapy. As a result, this technique is not widely used in radiation therapy.

Subject Selection and Description

Research written about electron therapy, the use of bolus in radiation therapy and BolusECT\(^\circledR\) will provide the bulk of the information for this study. Discussions with physicists and physicians will also be used. Cancer patients’ cases that have been treated at Northwestern Lake Forest Hospital will be retrospectively reviewed. Six patient cases were chosen for review. All cases were treated with BolusECT\(^\circledR\) over the course of 18 months. The treatment areas include: anus, left index finger, left shin, forehead, left pinnae and right external ear. All patients were treated to 60 Gy over 24 treatments.

Patient 1- Patient 1 is a 52 year-old female with microscopically invasive squamous cell carcinoma arising form verrucous carcinoma of the perianal skin. Complete surgical removal was felt to be quite difficult and would require reconstruction and skin grafting. This may have lead to long-term compromise of anal function. Radiotherapy was felt to offer the patient the best
chance of minimal dysfunction in the long-term. BolusECT® was chosen by the RO as the lesions were close to the skin surface and on a sloping surface.

**Patient 2**- Patient 2 is a 73 year-old male with a several month history of an enlarging lesion on the left index finger. Biopsy showed that the lesion was a basal cell carcinoma. The lesion was initially treated with topical chemicals with little success. Surgery was not an option due to the probable loss of function of the finger. BolusECT® was chosen as a result of the lesion wrapping around the finger and to increase the dose towards the surface. Standard electron beam therapy would have necessitated the use of multiple matching fields due to the steep slope on either side of the finger.

**Patient 3**- Patient 3 is a 92 year-old male with recurrent basal cell lesions on the left pinnae. Traditional bolus would have not been able to conform to the pinnae like BolusECT®. BolusECT® could provide homogenous dosimetry for this uneven surface.

**Patient 4**- Patient 4 is a 33 year-old female with multiple recurrent basal cell carcinomas on the forehead. The patient had the lesions removed and was referred for external beam therapy due to the multiple recurrences. The RO chose to treat with BolusECT® due to the sloping surface of the forehead and the ability to treat all the lesions in one field.

**Patient 5**- Patient 5 is an 83 year-old woman with a non-healing lesion of the left anterior tibia. The pathology was positive for squamous cell carcinoma. The patient also had in-situ squamous cell carcinoma in the biopsy specimens. The patient was not a surgical candidate due to the size of the lesion. BolusECT® could offer the best chance of local control and to limit the dose the bone. Using BolusECT® also allowed for the whole lesion to be treated in one field instead of the multiple fields that would be needed in standard electron beam therapy due to the slope of the patient surface. BolusECT® increased the dose to the skin surface and away form the bone.
Patient 6- Patient 6 is a 95 year-old male with a squamous cell carcinoma of the helix of the right ear. The patient had multiple lesions removed from the right ear in the past. The lesions continued to regrow and ultimately caused a large non-healing lesion of the helix. The patient declined further surgery. BolusECT® was chosen because of the improved dose distribution in irregular areas such as the helix of the ear.

Instrumentation

The instrumentation for this research includes a retrospective review of patient cases. Research on BolusECT®, electron therapy and bolus in radiation therapy will be analyzed. The author will also interview the physicist who was instrumental in the development of BolusECT® as well as physicians who have used BolusECT® in the treatment of cancer patients. The author will also be in contact with .decimal™ who manufactures the wax compensators used in BolusECT®. CMS’s XiO® treatment planning system versions 4.50.00 and 4.60.00 were used to plan the patients selected for this research. .decimal’s p.d software version 2.2 was used for BolusECT® design.

Treatment Planning

Use of BolusECT® necessitates that three treatment plans to be completed. A pre plan is done to give the medical dosimetrist an idea of the energy to be used and to get information to the p.d. software. An intermediate plan is used to verify the BolusECT® being made is acceptable and a post plan is used to verify the BolusECT® made is acceptable and to make any changes in energy.

An initial simulation is performed with the patient in the treatment position. The images are sent from the simulator to the TPS. The medical dosimetrist contours the skin. The Radiation Oncologist (RO) may or may not draw a tumor volume. A simple open field covering the area to be treated is applied using the appropriate electron energy. The goal is to cover the area to be
treated with the 90% isodose line. At this point the information is transferred to the p.d. software version 2.2 where the BolusECT® is designed. The structures and plan are imported into p.d. The tumor volume is chosen as the structure of interest. The medical dosimetrist places a 2 cm margin around the tumor and the 90% isodose line as the line of interest. The electron energy is chosen and the BolusECT® is created. At this point the original structure set is replaced with a new structure set that included the BolusECT®. This data set is transferred to XiO for the purpose of the intermediate planning.

The intermediate plan is done utilizing the new data set including the BolusECT®. The BolusECT® is contoured and given a density of .92g/cm³. Because of the thickness of the BolusECT®, a source to skin distance (SSD) of 105cm is required. The medical dosimetrist then traces the outline of the BolusECT® to create the electron cutout. The patient returns for a re-simulation when the BolusECT® has been received from .decimal. The patient is positioned in the same initial treatment position. The medical dosimetrist and the RO are in the simulator to aid in the position of the BolusECT®. The BolusECT® is placed (Figure 2) and a treatment planning CT (TPCT) is completed. The TPCT is evaluated to see if there were any large air gaps between the BolusECT® and the patient. If there are significant air gaps the BolusECT® was repositioned to reduce air gaps and another TPCT is done. Again this was evaluated and when deemed acceptable the lasers are marked on the BolusECT®. The TPCT was sent to the TPS for final planning.

Starting with the same parameters as the intermediate plan, the final plan is completed. The medical dosimetrist contours the external surface, including the BolusECT®. The density difference between the patient external contour and the BolusECT® is taken into account by using heterogeneity correction. The same electron cutout is used, and the plan was calculated.
The RO is called in at this point to evaluate the plan. The RO will choose the isodose line for treatment. The day the patient returns for the first treatment the medical dosimetrist and RO are in the room to ensure correct placement of the BolusECT® and electron cutout. Per departmental policy, the medical dosimetrist observed the patient setup weekly to ensure that there was no change in patient contour that would necessitate a change in the BolusECT®.

**Data Collection Procedures**

A literature review on BolusECT® will be conducted. The history of the use of bolus in electron radiation therapy as well as the development of BolusECT® will be studied. The benefits and disadvantages of BolusECT® will also be reviewed as well as the clinical applications. The treatment plans of patients who have been treated with BolusECT® at Northwestern Lake Forest Hospital will be analyzed. Six patients treated with BolusECT® over the course of 18 months will be reviewed. The treatment areas include: anus, left index finger, left shin, forehead, left pinnae and right external ear. All patients were treated to 60 Gy over 24 treatments. Discussion with physicians in regards to patient selection criteria and the clinical uses will also be studied.

**Data Analysis.**

A comparison of patient plans using BolusECT® as well as a comparison of side effects and patient conditions at follow up will be analyzed. A discussion of the physicians’ opinion regarding the use of BolusECT® will also be presented.

**Limitations**

The limitation of this research is the lack of literature that directly pertains to BolusECT®. Also, as this procedure is not widely used across the United States, there is limited physician awareness of BolusECT® resulting in a limited patient database. The author will need to discover why this procedure is not being used. Is it a lack of knowledge of the procedure or do
physicians feel that it is not a valid procedure? Enough information will need to be gathered to discern whether the use of BolusECT® is beneficial to the patient or not.

Discussions with the manufacturer of the compensators may be biased as well as that of the physicist who helped develop BolusECT®. The author will need to be able to discern if there is any bias in those discussions.

The patient research of this study is limited to patients treated at Northwestern Lake Forest Hospital (NMLFH). This will not be a large enough sample to determine the findings as related to nationwide standards.

Summary

This research will offer a more broad perspective of the use of BolusECT®. The patient studies presented will demonstrate NMLFH’s experience with the use of BolusECT®. The side effects as well as the benefits of using BolusECT® will be discussed. Previously written articles regarding electron therapy, the use of bolus in radiation therapy and BolusECT® provided the majority of the information for this research.
Chapter IV: Results

Six patient cases were chosen for review. All cases were treated with BolusECT® over the course of 18 months. The treatment areas include: anus, left index finger, left shin, forehead, left pinnae and right external ear. All patients were treated to 60 Gy over 24 treatments. The patients were evaluated based on isodose distribution and side effects. Using BolusECT® allows the medical dosimetrist to shape the isodose distribution to the treatment area. It also allows for underlying tissues to be spared dose. A single electron beam may now be used in areas where multiple beams were used previously. BolusECT® reduces the need for matching fields. As a result under dosing or overdosing of tissue is greatly reduced.

Item Analysis

Patient 1 is a 52 year-old female with microscopically invasive squamous cell carcinoma arising form verrucous carcinoma of the perianal skin. Complete surgical removal was felt to be quite difficult and would require reconstruction and skin grafting. This may have lead to long-term compromise of anal function. Radiotherapy was felt to offer the patient the best chance of minimal dysfunction in the long-term. BolusECT® was chosen by the RO as the lesions were close to the skin surface and on a sloping surface. The pre-plan was performed using 12 MeV electrons. The gantry angle was 320°, the collimator was 0° with a base angle of 90°. The pre-plan (Figure 3) shows the lack of coverage at the surface of the patient. The BolusECT® was designed and applied to the original patient contour and a virtual plan was performed. The beam energy was changed to 15 MeV to ensure coverage of the tumor volume. The gantry angle was changed to 310° to allow the beam to be enface to the treatment area. The collimator and base angles stayed the same. A final plan was designed upon receiving the custom bolus for Bolus ECT. The same gantry, collimator and base angle were used as in the virtual plan. The virtual
(Figure 4) and final plan (Figure 5) show that the 90% isodose line covers the surface of the patient. The final plan demonstrates that the coverage is better laterally with the BolusECT®.

Patient 1 failed to come in for the initial two-week follow up. At 5 weeks post therapy the patient did return to be seen by the RO. The RO noted that the patient experienced severe pain and desquamation the first 3 weeks post treatment. However at 5 weeks the patient was steadily improving. The patient still had some serosanguineous oozing in the treatment area. On exam the RO noted good healing except in the area of the gluteal fold. This was felt to be as a result of the gluteal fold rubbing and causing new growth to rub off. There was no sign of disease or recurrence. The patient did not come in for follow up again until 6 months post treatment. At that time the patient still noted some pain. The RO observed that 85% of the skin was now healed and that there was no evidence of persistent or recurrent disease.

Patient 2 is a 73 year-old male with a several month history of an enlarging lesion on the left index finger. Biopsy showed that the lesion was a basal cell carcinoma. Surgery was not an option due to the probable loss of function of the finger. BolusECT® was chosen as a result of the lesion wrapping around the finger and to increase the dose towards the surface. Standard electron beam therapy would have necessitated the use of multiple matching fields due to the steep slope on either side of the finger. The original plan was performed utilizing 6 MeV electrons with a 0° gantry, collimator and base angle. The 90% isodose line covered the tumor volume that was drawn by the RO. When the virtual BolusECT® was applied for the virtual plan it was necessary to increase the energy to 9 MeV electrons for the 90% isodose line to cover the tumor volume. When the actual BolusECT® compensator was applied for the final plan the 90% isodose line covered the tumor volume utilizing 9 MeV electrons. Gantry, collimator and base angles remained at 0° across all three plans. Figure 6 and 7 demonstrate the ability to sculpt the
isodose curve around the bone with the use of BolusECT®. The final plan also demonstrates a sharper peak of the isodose curve as compared to the virtual plan (Figure 5). As the patient’s tumor wrapped around the bone on both sides this provided a better treatment plan.

Patient 2 demonstrated brisk erythema and edema at the end of treatment as well as some moist desquamation. At the six week follow up there was mild erythema. The edema and desquamation had resolved. At three months the patient demonstrated complete healing. The only residual side effect was limited range of motion in the finger.

Patient 3 is a 92 year-old male with recurrent basal cell lesions on the left pinnae. Traditional bolus would not be able to conform to the pinnae like BolusECT®. BolusECT® could provide homogenous dosimetry for this uneven surface. The patient was rolled onto the right side to aid in positioning of the BolusECT®. The electron energy chosen for the pre-plan was 6 MeV with a gantry angle of 350°. The 90% isodose line covered the tumor volume drawn by the RO. The BolusECT® was designed and applied to the patient contour. The same electron energy was used to perform the virtual plan. For the virtual plan the 85% isodose line was chosen. As seen in Figure 9 the 85% isodose line provided better coverage. The final plan (Figures 10 and 11) also demonstrates the ability to draw the dose toward the skin and away from underlying tissues. Patient 3 demonstrated brisk erythema and moist desquamation to the treatment area and was completely healed at the six-week follow up appointment.

Patient 4 is a 33 year-old female with multiple recurrent basal cell carcinomas on the forehead. The patient had the lesions removed and was referred for external beam therapy due to the multiple recurrences. The RO chose to treat with BolusECT® due to the sloping surface of the forehead and the ability to treat all the lesions in one field. All three plans were designed utilizing 6 MeV electrons. The gantry, collimator and base angle was 0° in the pre, virtual and
final plan. Figures 12 and 13 show the ability to encompass multiple lesions in one field. This would not have been possible in a single field with conventional bolus due to the slope of the forehead. Multiple fields, with multiple gantry angles would have needed to been used. Figure 14 demonstrates how the 90% isodose line follows the contour of the forehead and provides an even dose distribution.

Patient 4 demonstrated the same brisk erythema and edema as the other patients at the end of treatment. The patient also demonstrated a significant tumor response, which consisted of scabbing in the area of tumor. At the two-week follow up the patient continued to have significant erythema as well as scabbing. At six weeks the patient only had slight erythema and the scabbing had resolved.

Patient 5 is an 83 year-old woman with a non-healing lesion of the left anterior tibia. The pathology was positive for squamous cell carcinoma. The patient also had in-situ squamous cell carcinoma in the biopsy specimens. The patient was not a surgical candidate due to the size of the lesion. BolusECT® could offer the best chance of local control and to limit the dose the bone. Using BolusECT® also allowed for the whole lesion to be treated in one field instead of the multiple fields needed in standard electron beam therapy due to the slope of the patient surface. BolusECT® increased the dose to the skin surface and away form the bone. Again the medical dosimetrist was able to utilize the same energy (12 MeV electrons), gantry, collimator and base positions in all three plans (Figures 14-18). The 90% isodose line covered the area to be treated completely in the virtual and final plans. The final plan (Figure 18) for the shin patient shows the ability to create a plan where the isodose lines conform to the desired treatment area, as well a provide coverage laterally on a sloping surface.
Aside from patient 1, patient 5 demonstrated the most side effects. At the completion of treatment the patient had brisk erythema and moist desquamation. At two weeks the desquamation continued as well as the erythema. At four weeks the erythema had resolved but the moist desquamation was still present. At the six month follow up this patient still had considerable moist desquamation. The patient had been massaging the leg pushing the fluids toward the treatment site. This was felt to have contributed to the lack of healing.

Patient 6 is a 95 year-old male with a squamous cell carcinoma on the helix of the right ear. The patient had multiple lesions removed from the right ear in the past. The lesions continued to regrow and ultimately caused a large non-healing lesion of the helix. The patient declined further surgery. BolusECT® was chosen because of the improved dose distribution in irregular areas such as the helix of the ear. The pre-plan was performed utilizing 6 MeV electrons with a 0° gantry angle. The 90% isodose line covered the treatment area. The virtual plan also utilized 6 MeV electrons. The gantry angle was 352° to provide a enface beam to the patient surface (Figures 19-20). When the final plan was done with the BolusECT® in place the electron energy needed to be changed to a combination of 6 MeV and 9 MeV electron beams. The 6 MeV beam provided 63% of the dose and the 9 MeV beam provided 27%. This allowed for the 90% isodose line to cover the treatment area desired. The final plan shows (Figures 21-22) the ability to create a homogenous dose distribution in an irregularly shaped area. Patient 6 demonstrated brisk erythema and moist desquamation to the treatment area. Patient 6 was completely healed at the six-week follow up appointment.

Patient 1 demonstrates how BolusECT® not only acts as bolus drawing the dose to the skin but also has the added benefit of acting as a missing tissue compensator. Patients 2 and 5’s isodose lines show the BolusECT® conforming the dose around an underlying structure. Patient
3 and 6’s show BolusECT® made the dose distribution more homogeneous in an area that is irregularly shaped. Patient 4 also demonstrates BolusECT®’s ability to provide a homogeneous dose in a sloped area by acting as a compensator. All six patients isodose plan demonstrate BolusECT®’s ability to allow the user to treat with a single electron field areas that would previously need multiple matching fields with standard electron beam therapy due to size of the field or irregular surfaces.

At the completion of treatment all six patients had brisk erythema at the treatment site. Five of the patients had considerable amounts of moist desquamation. At the six week follow up four of five patients with moist desquamation had almost none or were completely healed. By the six month follow up all the patients except for Patient 5 were completely healed. Patient 5 still continued to have issues in the shin treatment area.

When comparing the side effects of patients treated with BolusECT® at Northwestern Lake Forest Hospital experienced, the most prevalent side effect was moist desquamation. The moist desquamation that was experienced was comparable to that of patients treated with conventional bolus. The advantage of using BolusECT® was that the custom bolus could be conformed to the patient surface exactly. Conventional bolus, although flexible, does not conform as easily or exactly and may lead to air gaps. The other advantage is using a single electron bolus field versus multiple matching electron fields used in conventional electron therapy.
Chapter VI: Discussion

The purpose of this study was to demonstrate the use of BolusECT® in radiation oncology. Data was collected through literature review and a retrospective study of patients that were treated with BolusECT® at Northwestern Lake Forest Hospital over an eighteen month time period. The .decimal website describes BolusECT® an advantageous method for treating superficial target volumes with a single electron beam using a variable thickness tissue compensator. BolusECT® can create a favorable dose distribution for tumors of the chest wall, head and neck and other sites where the tumor volume exists near the patient surface, as well as areas where critical structures underlay the PTV. This was clearly demonstrated in the six patient’s presented.

Limitations

This research was limited by the lack of literature devoted to BolusECT®. The compensator manufacturer’s website has information regarding BolusECT® but it does not provide an exhaustive review. As a result of limited literature available, BolusECT® is not being widely used which diminishes the database available for this literature review. The research was further limited in that only one institutions experience with BolusECT® was presented.

Conclusion

Planning for BolusECT® is a time consuming process. There is a minimum of two treatment planning simulations that need to be done as well as three treatment plans. The medical dosimetrist needs to be available for simulation and for BolusECT® placement. The RO must be available to verify BolusECT® placement as needed. It also requires a dedicated team of therapists that are willing to take the time to properly place the BolusECT® each day. The medical dosimetrist may have to use SSD’s that are normally not utilized. The placement of
BolusECT® is not easily completed. The RO needs to keep a close eye for increased skin reactions when using the product. There is the potential for the patient to require re-planning if the external contour changes and the BolusECT® no longer fits. Being flexible is part of planning with BolusECT. Many times the medical dosimetrist may start planning with a specific energy but end with a different energy.

As mentioned previously, the most prevalent side effect of the patient case studies was moist desquamation. The moist desquamation experienced was comparable to that of patients treated with conventional bolus. The advantage of using BolusECT® is the ability to conform dose to the patient surface by customizing the treatment device for each patient treatment. By using BolusECT®, Dr. Marc Posner, Radiation Oncologist at The Center for Advanced Radiation Medicine at Northwestern Lake Forest Hospital, stated that the dose is more homogenous and conformal to the tumor volume. BolusECT® improves upon sub-par plans that patients would have previously received. Using BolusECT® eliminates air gaps between the bolus and patient surface. The user has the ability to sculpt the dose as needed through BolusECT®. This is done by designing a BolusECT® that is thicker in some areas while thinner in others. Another major advantage that Dr. Posner identifies is the use of a single field where multiple fields may have been previously used. When treating with multiple matching fields there is the risk of an area being either over or under dosed, which is eliminated when using BolusECT® giving the physician a “peace of mind”.

**Recommendations**

Further research into the use of BolusECT® is needed. The few benefits that conventional bolus has over BolusECT® includes the ability to be reused, lower costs, and that it is readily available. These are significantly outweighed by the benefits of BolusECT®. By using
BolusECT® it has been demonstrated that the isodose curves can be conformed to the treatment area while preserving underlying tissues. Research in using variable tissue compensators in conjunction with IMRT is also needed. Combining multiple modalities may provide more control over the DVH and produce more optimal plans. The use of BolusECT® has not been fully explored at this time. Through further research, developing treatment techniques utilizing BolusECT® will prove to be beneficial for patients with superficial lesions. More studies need to be completed utilizing BolusECT® so that it may be used to its fullest potential.
Figures

Figure 1. Example of BolusECT®. Courtesy of decimal®

Figure 2. Custom made BolusECT® for Patient 1. Courtesy of the Center for Advanced Radiation Medicine, Northwestern Lake Forest Hospital
Figure 3. Pre-plan anal patient. Courtesy of the Center for Advanced Radiation Medicine, Northwestern Lake Forest Hospital

Figure 4. Intermediate (virtual) plan anal patient. Courtesy of the Center for Advanced Radiation Medicine, Northwestern Lake Forest Hospital
Figure 5. Final plan anal patient. Courtesy of the Center for Advanced Radiation Medicine, Northwestern Lake Forest Hospital

Figure 6. Virtual plan of left index finger patient. Courtesy of the Center for Advanced Radiation Medicine, Northwestern Lake Forest Hospital
Figure 7. Final plan of left index finger patient transverse slice. Courtesy of the Center for Advanced Radiation Medicine, Northwestern Lake Forest Hospital

Figure 8. Final plan of left index finger patient sagittal slice. Courtesy of the Center for Advanced Radiation Medicine, Northwestern Lake Forest Hospital
Figure 9. Virtual plan of left pinnae of the ear patient. Courtesy of the Center for Advanced Radiation Medicine, Northwestern Lake Forest Hospital

Figure 10. Final plan of left pinnae of the ear patient transverse slice. Courtesy of the Center for Advanced Radiation Medicine, Northwestern Lake Forest Hospital
Figure 11. Final plan of left pinnae of the ear patient sagittal slice. Courtesy of the Center for Advanced Radiation Medicine, Northwestern Lake Forest Hospital

Figure 12. Virtual plan of forehead transverse slice. Courtesy of the Center for Advanced Radiation Medicine, Northwestern Lake Forest Hospital
Figure 13. Virtual plan of forehead sagittal slice. Courtesy of the Center for Advanced Radiation Medicine, Northwestern Lake Forest Hospital

Figure 14. Final plan forehead patient. Courtesy of the Center for Advanced Radiation Medicine, Northwestern Lake Forest Hospital Patient 5- Virtual plan and final plan 12 MeV electrons.
Figure 15. Virtual plan of shin transverse slice.Courtesy of the Center for Advanced Radiation Medicine, Northwestern Lake Forest Hospital

Figure 16. Virtual plan of shin sagittal slice. Courtesy of the Center for Advanced Radiation Medicine, Northwestern Lake Forest Hospital
Figure 17. Final plan of shin transverse slice. Courtesy of the Center for Advanced Radiation Medicine, Northwestern Lake Forest Hospital

Figure 18. Final plan of shin sagittal slice. Courtesy of the Center for Advanced Radiation Medicine, Northwestern Lake Forest Hospital
Figure 19- Virtual plan of right external ear transverse slice. Courtesy of the Center for Advanced Radiation Medicine, Northwestern Lake Forest Hospital

Figure 20- Virtual plan of right external ear sagittal slice. Courtesy of the Center for Advanced Radiation Medicine, Northwestern Lake Forest Hospital
Figure 21- Final plan of right external ear transverse slice. Courtesy of the Center for Advanced Radiation Medicine, Northwestern Lake Forest Hospital

Figure 22- Final plan of right external ear sagittal slice. Courtesy of the Center for Advanced Radiation Medicine, Northwestern Lake Forest Hospital
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