The Evolution of the Robotic Systems for Prostate Radioactive Seed Implants in Low-Dose-Rate Brachytherapy

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1. Introduction

Automation is not only present in the industrial area, but also in medicine. From the production of drugs to robotic prostheses implants in injured or disabled patients. In addition,, automation helps physicians in surgical procedures, in robotic surgery; creates automatons responsible for monitoring the position of patients in radiotherapy treatments; and interacts with artificial intelligence software to assist the medical diagnosis and therapy [2]. An area of medicine that has stood out in recent decades with the help of automation is laboratory medicine [1, 3].

Robotic systems for implants of radioactive seeds in prostate, low-dose-rate brachytherapy, have been developed in different research institutes and hospitals around the world [4]. These robotic systems are mainly based on automating the technique of inserting a surgical needle and distributing or placing radioactive seeds in the desired region. In such procedure, these robotic systems are in contact with patients and are close to the medical team. Therefore, safety, precision, friendly interfaces and reliability criteria need to be satisfied for any robotic brachytherapy system. The functional requirements of the robotic brachytherapy system must provide safety for the patient, physicians, operator, and to equipment in the room. The surfaces fo the robot shall be ease of cleaning and decontamination, compatibility with chemical substance use on sterilization. The system shall held methods for the clinician to review and approve the plan of dose distribution and the plan of robot movements before needle placement. The whole system shall have visual (mandatory) and forced (optional) feedback during needle insertion. The redundant visual confirmation shall have choice of image technique for following each needle tip placement and seed deposition, willingness to reverse for the conventional manual method at any time. The system shall be prepared to quick and easy disengagement in case of emergency. It shall be robust and reliable operation, and ease of operation in the clinical environment [4, 9].

The present research proposed, based on a literature review, to illustrate the evolution of the development of robotic systems to aid radioactive seed implants in the prostate in low-dose-rate brachytherapy treatment in hospitals and research centers.

2. Methodology

A digital search was performed on July, 2021, in the MEDLINE database to retrieve articles published during the last five years on the field of "robotics" and "radiation therapy" and "brachytherapy". A set of articles was selected and reviewed, separating them from international research institutes [4, 5, 9] and from Brazilian researchers [6, 7, 8].

3. Results and Discussion

3.1 International research on brachytherapy automation

In the literature, studies related to the development of robotic systems for implants of radioactive seeds for treatment by low-dose-rate brachytherapy in the prostate were present. These studies are concentrated on the Asian and European continents in research centers and hospitals [4].

So far, 13 robotic systems have been developed for brachytherapy. However, they differ from each other with respect to the available features, functionalities and levels of automation.

POPESCU *et. al*., (2015) conducted a study on the state of the art of robotic systems under development for radioactive seed implants in the prostate in low-dose-rate brachytherapy. The authors investigated the main differences between them. The Table 1 summarized this information in according to POPESCU et al, 2015. The Table I summarizes the most current available robotic brachytherapy systems [4].

Table I: Summary of the currently availabre robotic brachytherapy systems [9].

Robotic brachytherapy systems	***Aplication***	***Number of channel / needle***	***Needle rotation***	***Angle insertion***	***Seed delivery***	***Accuracy in seed deposition***	***Needle – tip positioning accuracy in phantom***	***STOP emergency***
FIRST	PSI	Single	No	No	Autonomous	< 1 mm (tested)	< 0.5 mm	Yes
EUCLIDIAN	PSI	Single	Yes	Yes	Autonomous	< 1 mm (tested)	< 0.5 mm	Yes
MIRAB	PSI/HDR	Multiple	Yes	-	Autonomous	< 1 mm	< 0.5 mm	Yes
UMCU	PSI/HDR	Single	No	Yes	Manual	-	-	Yes
UW robot	PSI/HDR	Single	Yes	Yes	Manual	< 1 mm	-	Yes
JHU1 – robot1	PSI	Single	No	Yes	Manual	-	1.04 mm	Yes
JHU2- MrBot	PSI	Single	No	No	Autonomous	< 1 mm	< 0.5 mm	Yes
JHU3- MrBot	PSI	Single	No	Yes	Manual	-	2.0 mm	Yes
JHU and BWH -MR	PSI	Single	No	Yes	Manual	-	3.0 mm	Yes
UBC	PSI	Single	No	Yes	Manual	1.2 mm	-	Yes
RRI	PSI	Single	Manual	Yes	Manual	1.6 mm	0.9 mm	Yes
CHUG	PSI	Single	Yes	Yes	Manual	-	1.0 mm	Yes
MIRA-V	LSI	Single	No	Yes	Manual	-	0.9 mm	Yes

Note: PSI, prostate source implantation; LSI, lung source implantation.

The most relevant works found in the literature in the structural construction of an automatic radioactive seed implant system in low-dose brachytherapy treatment is listed below. Other works were found in the literature, but they are studies related to the improvement of these system with respect to precision, accuracy of the positioning of needles and radioactive seeds and other characteristics that are considered essential for receiving approval for use in human patients by the committee of ethnicity and health.

YU *et. al.* (2006) developed a robotic radioactive seed implantation system for prostate brachytherapy guided by transrectal ultrasound image. The robotic system has two translation movements, in the x and y directions, and a rotation movement in the vertical plane, to avoid interference from the pubic arch. Figure 1 illustrates the robotic system developed by YU *et. al*.- EUCLIDIAN robot for brachytherapy [5].

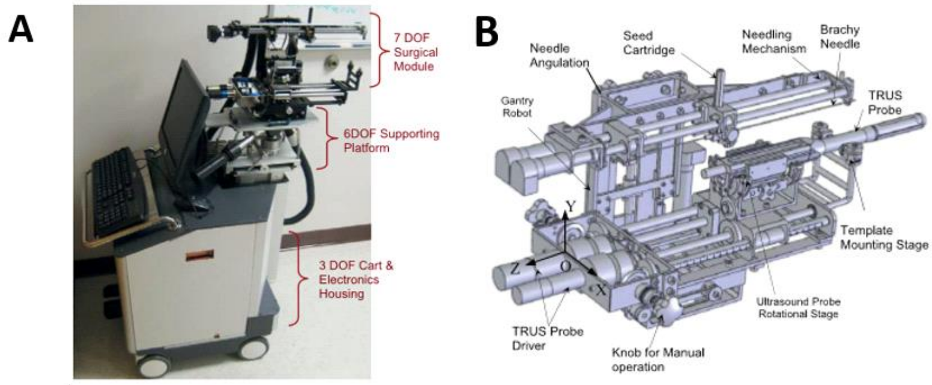

Figure 1: EUCLIDIAN robot for brachytherapy: (A) three modules are surgical, supporting and, cart and electronic housing; (B) 3D solidWork design of surgical module.

Source: [9]

This robotic system is under development in improvement tests for approval by the medical ethics board and pertinent legislation. Commercialization is not yet possible [4].

3.1 National research on brachytherapy automation

In Brazil, research is in progress for the development of robotic systems to aid radioactive seed implants in the prostate in low-dose-rate brachytherapy treatment, that will be reviewed here. Some of the studies use a robotic arm to position the seed insertion mechanism or use the ultrasound probe insertion mechanism semi-automatically and with the positioning and insertion of seeds performed manually.

JÚNIOR *et. al.* (2018) in entitled “Automation of implantation of radioactive seeds for brachytherapy” proposed the development of a simulator, the implementation of programming logics, for the industrial robot and for the Arduino Uno prototyping board used in the double-stage tool. Seed and spacer positioning tests were carried out in specimens produced with ballistic gelatin. According to the author, through the tests carried out, the capacity of the system to perform the seed implantation in a safe, precise, and automatic way was verified, and this implant followed exactly the position defined in the treatment planning stage [8].

SILVA *et. al.* (2019) addressed the development of an automatic radioactive seed implantation system (Prostate Seed Implant System - PSIS). PSIS may assist the testing permanent implants procedure in the prostate. These tests will be important in measurements of absorbed doses in the pelvic structures, involving the organs and tissues at risk to improve planning, seed positioning and dosimetry. The automated Prostate Seed Implant System has been designed to meet operational needs, which offers the freedom when positioning the brachytherapy needle inside the treatment area ensuring repeatability and fidelity to the planned treatment. The advantage of this system is that the automation of the application provides an accurate positioning and movement of both probe and seed application. In addition to this study, seeds implantation tests will be performed, and such tests will be essential in protocol validation processes [6].

In SILVA *et. al.* (2021), the improvements of the prototype of the Prostate Seed Implantation System (SISP), developed by the Nuclear Engineering Department of the UFMG (Nuclear Engineering Department) were presented. The device allows automated scanning on x, y and z axes, facilitating the application of radioactive seeds in prostate brachytherapy treatments, which in current treatments are done manually by the clinician. Also, the possibilities of controlling the needle movements via Bluetooth technology were implemented [7].

4. Conclusions

Application of robotic systems in brachytherapy is a developing field and it is premature to make strict recommendations at this time. The authors expect near future the robotic systems will become standardized for brachytherapy procedures and some of the systems will be evaluable to hospitals and clinics.

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