INTRODUCTION
Prostate cancer accounts for 28% of newly diagnosed cancers and typically occurs in older men over the age of 40. It is a leading cause of cancer death among men in the United States [1] and also Europe. For diagnosis, patients with prostate-specific antigen (PSA) levels greater than 4ng/mL or with suspicious results on digital rectal examinations are encouraged to undergo prostate biopsy [2]. The results of first transrectal ultrasound (TRUS)-guided prostate biopsy, however, prove to be negative in 66% of patients with PSA levels greater than 4ng/mL and it has been estimated that about 15% to 31% of a standard sextant sampling are falsely negative [2,3,4,5,6]. This occasionally leads to repeated TRUS-guided prostate biopsies without definitive diagnosis. A false-negative result may be the result of sampling error intrinsic to the sextant sampling [7,8,9,10,11,12]. Increasingly, the relatively low sensitivity of TRUS-guided prostate biopsy is being questioned and alternative approaches to TRUS-guided biopsy are being pursued [11,13,14]. Magnetic resonance image (MRI)-guided and MRI-targeted TRUS-guided biopsy are alternative methods to TRUS-only-guided biopsy for detecting and diagnosing prostate cancer. This is especially true for men with multiple negative TRUS-only-guided prostate biopsy results despite high PSA levels [15,16]. In a recent study, MRI-guided biopsy detected cancer in 71% of patients who had received at least 1 negative TRUS-only-guided prostate biopsy result [10]. Published values for MRI-guided biopsy range from 51% to 59% in literature [17,18]. For MRI-targeted TRUS-guided biopsies, the diagnostic rates have been reported as 62.9% in [19] and 69.7% in [20].

ROBOTIC DEVICES
To further enhance MRI-guided biopsy, robotic devices have been introduced to improve needle placement accuracy with the goal of improving diagnostic yield [21, 22]. Multiple MRI-compatible robotic devices for transrectal and transperineal biopsies have been introduced and applied clinically. Such robotic devices have been shown to give improved results [23,24,25]. Evaluation of the performance of transperineal robotic devices, however, has so far been limited to phantom or animal studies and have not been clinically used for MRI-guided biopsies [26,27,28,29]. A recent review article [30] expressed concern that the clinical usefulness of MRI-compatible robotic devices remained to be seen in MRI-guided biopsies of prostate.

Therefore, in a paper recently published by our team, we reported the results of clinical deployment of a robotic needle-guidance template for in-bore 3T transperineal MR-guided prostate biopsy [31]. This study described the utility of a robotic needle-guidance template for in-bore 3T transperineal MR-guided prostate biopsy by comparing manual and robotic biopsies through a two-arm mixed retrospective-prospective study.

The article presents the highlight findings from this study [31].

BIOPSY PROCEDURE
A 3 Tesla wide-bore MRI scanner (MAGNETOM Verio 3T, Siemens AG, Erlangen, Germany) was used in all biopsy procedures. Detailed descriptions of the manual approach and the robotic approach are described in [32] and [33] respectively.

The manual approach utilized a manual needle guidance template comprised of a grid of holes 1.3mm in diameter and spaced 5mm apart. A planning and navigation software, 3D Slicer (www.slicer.org), was used to plan which guide hole would be used for needle insertion and how deep to insert the needle for each core sample collection [34].

The robotic approach used a motorized robotic needle-guidance template, which can set the needle insertion hole with a control resolution of 0.001mm [33]. During the robotic approach, the 3D Slicer software was modified to issue a motion control command to the robotic needle-guidance template to align the needle insertion hole to the transperineal needle placement trajectory. A confirmation image was taken using axial 2D multi slice Turbo Spin Echo after clinicians inserted the needle.

ROBOTIC NEEDLE GUIDE
Two ultrasonic motors with integrated optical encoders are used in the robot. The motor rotations are
transmitted to vertical and horizontal prismatic motion of each cross bar by a leadscrew-and-nut mechanism. A needle insertion position is created on the axial plane of the template by the cross point of the bars. The structural body of the motorized template is made of brass alloy screws and Ultem resin. Timing-belts, pulleys, and miter-gear set compose the non-ferrous transmission parts.

The 3D Slicer, an open-source surgical navigation software, was extended with the ProstateNav module to calibrate the robot to images, plan needle placement to targets, monitor the position of inserted needles and also to control the motorized template remotely [32].

**CLINICAL STUDIES**

Our study was conducted with 96 patients in 99 cases; 43 of these cases were performed using the robotic template and the remaining 56 cases were performed using the conventional needle guide template. The average age of the patients was 66.01 (±6.81) years, the median prostate-specific antigen level was 8.50 ng/mL, and the median prostatic volume was 42.75 cc. There was no statistically significant difference in patient characteristics between the manual and robotic groups.

For each procedure, a log file was kept for analysis. For 88 cases, 47 manual and 41 robotic, image-based accuracy analyses was performed. In addition, the “core” procedure time was recorded in order to compare the procedure time between the robotic and manual approach. This “core” procedure time refers to the elapsed time between the registration image scan and the final image scan. In addition, the number of sample cores collected from each target was recorded as well. A core was considered as a positive cancer if, on pathology analysis it had a Gleason score of 6 or higher. This diagnostic record for each core is referred to as “diagnosis per core.” Additionally, the diagnosis for the subject was recorded as positive if one of the cores from the subject was cancer-positive; such a record is referred to as “diagnosis per subject.”

**FIGURE 1.** Robotic needle-guidance template set up in 3-T In-Bore MRI. Once the patient is laid down on the patient board and preparation at the perineum site is complete, the robotic needle-guidance template is screwed onto the patient board.

**FIGURE 2.** Comparison of the robotic needle-guidance template (left) and the manual needle-guidance template (right).
RESULTS
A significant statistical difference was found in the accuracy log when data regarding the best attempts of needle placement were analyzed. The robotic approach (2.39 mm) had statistically significant higher accuracy (p<0.027) compared to the manual approach (3.71 mm). Furthermore, the mean core procedure time for the manual group was 100.63 minutes whereas core procedure time in the robotic group was only 90.82 minutes. In comparison of the record of diagnosis per subject, no statistically significant difference existed between the manual and robotic groups; positive cancer was confirmed in 30 of 56 cases in the manual group (53.57%) and 25 of 43 cases in the robotic group (58.13%).

In studying the diagnosis per core, however, cancer was detected in 174 of 541 cores (32.16%) taken from patients in the manual group, while 137 of 310 cores (44.19%) taken from the robotic group was cancer positive. This suggests that the robotic approach has a greater chance of providing positive cancer core than the manual approach (p=0.018).

DISCUSSION
This study presents a quantitative comparative analysis of the accuracy of an MRI-guided prostate biopsy robot by comparing the clinical usage results of a robotic needle-guidance template to those from a manual template for in-bore 3T transperineal MR-guided prostate biopsy. Overall, the robotic needle-guidance template achieved better targeting accuracy, more positive tissue from the cancer core, and reduced core procedure time in comparison with the manual approach.

Usage of MRI guidance allows clinicians to employ intraoperative images to not only see the target, but also to adjust the needle position [30]. This function improved the accuracy of needle placements in both the robotic and manual approaches. However, there was a greater improvement in accuracy with the robotic template compared to the manual template (3.86 mm with the robot and 2.80 mm with manual placement in log-transformed values). These data show that the clinician is better able to fine-tune the needle position using the robotic template during MRI-guided biopsy.

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