Fiducials: Achilles' Heel of Image-Guided Neurosurgery: An Attempt at Indigenization and Improvement

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Image-guided surgery or neuronavigation has become an important part of the neurosurgical armamentarium in most centers around the world, primarily because it helps to improve patient safety and consistency of surgical results.[1–5,8] However, these advantages come at the cost of increased health care and patient expenses. The disposable products used in image-guided surgery are often very costly. In developing countries such as India, hospitals may find money for large capital purchases, but often fail to budget for the price of consumables over the lifetime of the product. The lack of availability of the consumables may lead to underuse of the equipment. At the All India Institute for Medical Sciences, the Medtronic StealthStation (Medtronic Sofamor Danek, Inc., Memphis, TN) is used for neuronavigation, and the disposable fiducials cost INR4200 (US$100) for every procedure in which the StealthStation is used. As the average cost of consumables in major cranial surgery at our center is INR15000 (US$350), using neuronavigation can increase these costs by 25% simply because of the cost of fiducials. We therefore attempted to find less expensive available indigenous alternatives to replace the proprietary fiducials used with the StealthStation in image-guided neurosurgery.

MATERIALS AND METHODS

The study was conducted in the Department of Neurosurgery, All India Institute for Medical Sciences, over a one-year period. The departmental ethics committee approved the study, and informed consent was obtained from all patients in the study. Various materials were tested for suitability for fiducial use in image-guided neurosurgery on the StealthStation system. The accuracy of registration for the indigenized fiducials was internally verified by the StealthStation by using the proprietary and the indigenized fiducials simultaneously on patients and was calculated as overall accuracy of registration (OAR) for each type of fiducial. The StealthStation automatically calculates the accuracy of the fiducials by comparing the system and patient registration data; hence, no external validity check is required. After extensive testing, the best indigenized fiducials (vitamin E) were used on selected patients undergoing neurosurgery. To compare the OAR between the two types of fiducials during neurosurgical procedures, a six-month period for each was chosen. The files of all patients who underwent image-guided surgery with proprietary fiducials in the six months before introduction of vitamin E were reviewed retrospectively. The plans stored on the StealthStation for all these patients were reviewed and the OAR retrieved. After introduction of vitamin E fiducials, the OAR was recorded for each patient prospectively for the next six months.

RESULTS

Various materials, including copper sulfate, milk fat, and vitamin E capsules were evaluated as potential materials for fiducials. We initially used copper sulfate paste by inserting it in a syringe and applying it while still wet to the scalp. It was allowed to dry, and magnetic resonance imaging (MRI) and computed tomography (CT) were performed. However, it was found to be poorly visible on the images and unsuitable for use as a fiducial. We next increased the concentration of the copper sulfate and filled vial caps that

FIGURE 15.1. Application of the vitamin E capsule is simple and does not require major preparation, as shown.
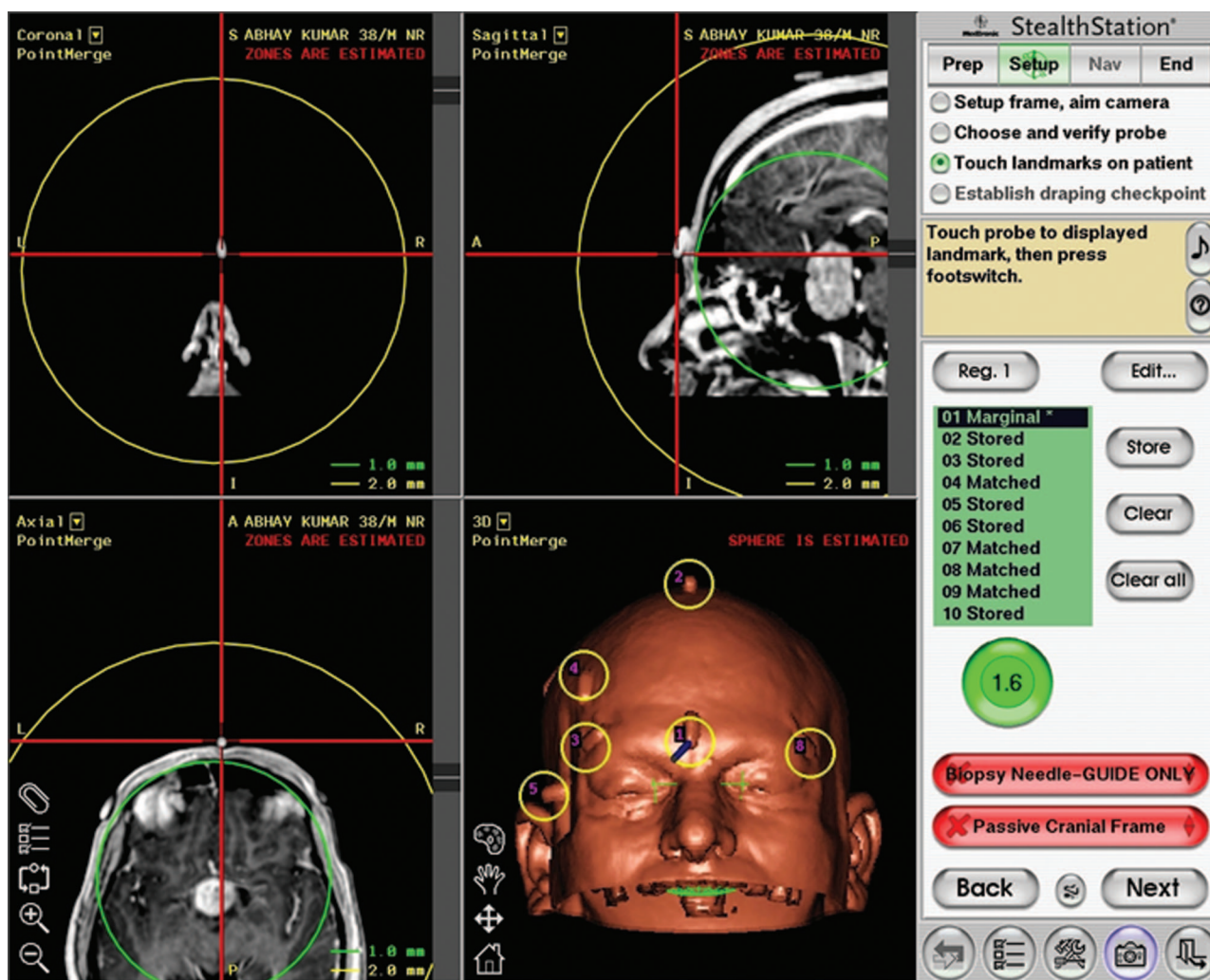
FIGURE 15.2. Screen view of an image-guidance system showing the magnetization-prepared rapid acquisition with gradient echo sequence of magnetic resonance imaging with 3-dimensinal reconstruction. The vitamin E capsules can be very well seen in all the planes, and the tip of the capsule can be localized accurately. Nav, navigation; Prep, preparation; Reg. 1, registration 1.

were affixed to the scalp. The visibility was better on CT and MRI but still suboptimal. Also there was no definable registration point available. We also used milk fat in small plastic cups, and although seen well on MRI, it was not visible on CT images. Vitamin E capsules were easy to affix to the scalp (*Fig. 15.1*) and were very well seen on MRI (T1-weighted, T1-weighted with contrast, and magnetization-prepared rapid acquisition with gradient echo sequences) (*Fig. 15.2*). The capsules were also nicely visible on a CT head scan (plain as well as contrast-enhanced images). The window, however, needed to be adjusted slightly on the CT images (which can be easily done on the image-guidance machine) to make the capsules stand out (*Fig. 15.3*). We found that registration of the capsule was fast and simple if the ends of the capsules were used instead of the usual point on the skin.

Technique for Using Vitamin E as Fiducials

Five to ten 400-IU vitamin E capsules are attached to the patient's scalp. The area of the skin where the capsule is to be attached is shaved and prepped with tincture of benzoin, which is allowed to dry. The capsule is placed horizontally on the skin and fixed with a small piece of Micropore adhesive tape (Johnson & Johnson Medical Inc., Arlington, TX) early in the morning before surgery. MRI and CT of the head are performed using standard protocols for image guidance, and the images are transferred to the StealthStation. The capsule is seen as hyperdense on CT and homogeneously hyperintense on standard MRI sequences (T1-weighted, T1-weighted with contrast, and magnetization-prepared rapid acquisition with gradient echo sequences) (*Fig. 15.3*). The two ends of the capsule can be marked as two separate fiducials on the
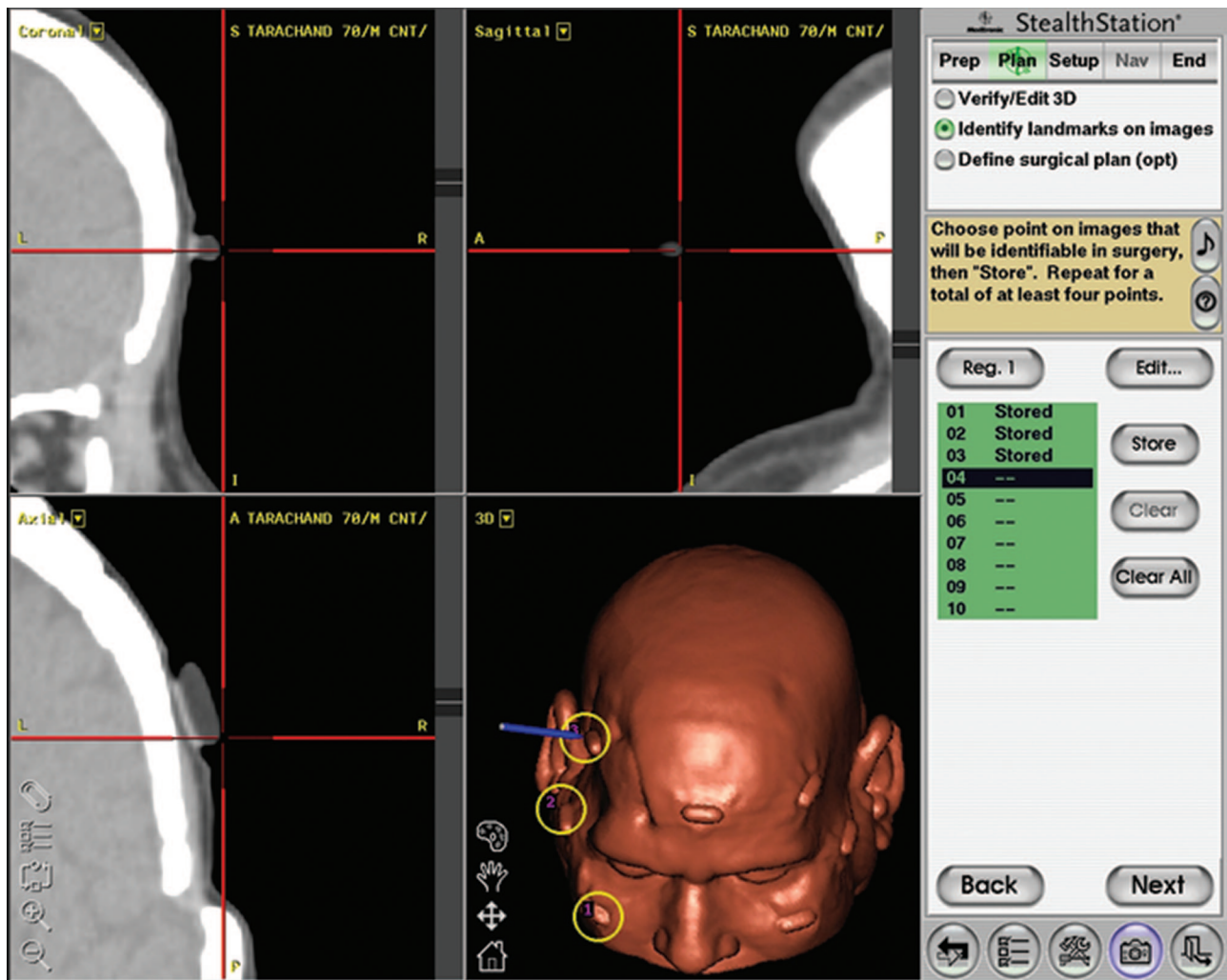
FIGURE 15.3. Visibility of vitamin E capsules on computed tomography (CT) images. The window of the CT needs to be adjusted to make the capsules stand out. 3D, 3-dimensional; Nav, navigation; Prep, preparation; Reg. 1, registration 1; opt, optional.

StealthStation. After induction of anesthesia, the patient's head is fixed in a Mayfield clamp, and the registration is done by touching the ends of the capsules instead of the skin. Because the StealthStation requires a maximum of 10 points to be registered, using both ends of five capsules provides the necessary data. However, in our experience, it is prudent to place eight to 10 capsules to provide flexibility in selecting the fiducials intraoperatively and also to provide a measure of redundancy.

Based on these results, vitamin E fiducials were used in neurosurgical operations. In a six-month period before the introduction of vitamin E, 22 patients underwent image-guided surgery with proprietary fiducials with a mean OAR of 2.41 mm (range, 2.1–2.9 mm). Over the next 6 months, 26 patients underwent image-guided surgery using vitamin E fiducials with a mean OAR of 1.84 mm (range, 1.2–2.8 mm).

The cost per procedure using vitamin E capsules varied from US$0.10 to 0.20 compared with US$100 for proprietary fiducials, a cost savings of more than 99%.

DISCUSSION

Image-guided neurosurgery is becoming more popular as it increases the accuracy and improves surgical results. However, widespread use has been limited in part by high capital costs of the equipment and the ongoing costs associated with maintenance and disposables such as fiducials. With improvement in technology, the equipment purchase costs are decreasing. In addition, hospitals such as ours have policies that require five- to 10-year maintenance contracts be built into the initial purchase price to help prevent early equipment obsolescence and recurring maintenance costs. Nevertheless, the cost of disposables remains a significant impediment to the optimal use of image-guidance systems in

developing countries such as India. We have been trying to overcome the high cost of disposable fiducials by using them more than once. Despite careful use, fiducials last a maximum of three to four procedures. The accuracy of registration also decreases when using worn-out fiducials. Another way to decrease the costs is by using fewer fiducials per procedure. However, this may also lead to decreased accuracy and is not recommended. Indeed, it has been shown that using fewer than eight fiducials leads to a decrease in final accuracy.[8]

The application accuracy of different neuronavigation systems critically depends on the registration.[7] Although recent image-guidance systems use surface registration, which obviates the need for fiducials, studies have shown that skin adhesive fiducial marker registration remains the most accurate noninvasive registration method to date.[6,7] Many hospitals around the world (such as ours) have older image-guidance systems that either do not support surface registration or have very cumbersome surface registration procedures.

A good fiducial should be easily affixed to the scalp and provide firm attachment at the point of contact. It should be clearly visible on CT and MRI and have definable points that can be registered. It is also desirable that the fiducial be inexpensive and nontoxic to the patient and the environment. Copper sulfate and milk fat did not meet all the requirements of a good fiducial, but vitamin E capsules were found to satisfy and even exceed all requirements. The most important feature of a fiducial is the ability to consistently and accurately register a point on itself with the images on the image-guidance system. Counterintuitively, the rounded ends of vitamin E capsules provide excellent registration accuracy, and both ends can be used as two separate registration points if necessary. Surprisingly, the mean overall accuracy was found to be better than the proprietary fiducials in our study. One of the possible reasons for the increased accuracy using the capsules is that the ends of the capsules rather than a point on the skin are used for registration. Touching the probe on the skin usually leads to pressure on the scalp with some underlying scalp movement, leading to decreased accuracy.

Although the current version of the StealthStation has tracer technology, which allows registration without fiducials in many cases, fiducial-based registration is always more accurate than surface registration[8] and may be the only option in certain cases such as posterior fossa surgery in which surface registration may not work.

CONCLUSIONS

Vitamin E capsules have proved to be an excellent alternative to proprietary fiducials used in image-guided neurosurgery. In our study, these indigenized fiducials were found to be as accurate as proprietary fiducials, providing more than a 99% savings in cost per procedure.

Disclosure

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