Review Article

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Haptics – Touchfeedback Technology Widening the Horizon of Medicine

Dentistry Section

SHALINI KAPOOR[1], PALLAK ARORA[2], VIKAS KAPOOR[3], MAHESH JAYACHANDRAN[4], MANISH TIWARI[5]

ABSTRACT

Haptics, or touchsense haptic technology is a major breakthrough in medical and dental interventions. Haptic perception is the process of recognizing objects through touch. Haptic sensations are created by actuators or motors which generate vibrations to the users and are controlled by embedded software which is integrated into the device. It takes the advantage of a combination of somatosensory pattern of skin and proprioception of hand position. Anatomical and diagnostic knowledge, when it is combined with this touch sense technology, has revolutionized medical education. This amalgamation of the worlds of diagnosis and surgical intervention adds precise robotic touch to the skill of the surgeon. A systematic literature review was done by using MEDLINE, GOOGLE SEARCH AND PubMed. The aim of this article was to introduce the fundamentals of haptic technology, its current applications in medical training and robotic surgeries, limitations of haptics and future aspects of haptics in medicine.

Keywords: Robotic surgeries, Tactile skills, Actuators, Virtual reality, Human-computer interaction

INTRODUCTION

Touch is the earliest sense which is developed in human embryology and it is believed to be essential for a good clinical practice [1]. The sense of touch (haptic) is a modality that we use too often in our day to day lives and its importance is eminent. Haptic (or force-feedback) devices are an innovation in the field of art that allow users to feel and touch objects with a great degree of realism [2]. Rapid growth has occurred in the areas of distance learning, interactive telecommunications, computer-assisted instructions, and computer simulations. HAPTICS-are also known as - VIRTUAL REALITY SYSTEMS. The word 'haptics' is derived from the Greek word, 'haptein', meaning "contact or to touch". It is the science of applying a tactile sensation which causes mechanical stimulation to create virtual objects in a computer simulation, to enhance the remote control of machines and devices (telerobotics) [3] [Table/Fig-1]. Haptics refers to sensing and manipulating through touch, enabling the user to touch and feel virtual reality (VR) or an existing distant object indirectly. This sensation can now be added to the current computer models which have sight and sound only. Haptics also provides forced feedback to those who interact with virtual or remote environments, so that a bi-directional flow of information is created. There are special devices like joysticks, data gloves, etc through which operators can receive feedback from computer applications in the form of sensations which are felt in any part of the body. In combination with a visual display, haptics technology can be used to train people for tasks which require hand-eye coordination, such as surgery and space ship manoeuvres [4]. Haptics allows the operator to "feel" and work around unseen obstacles through the eminent sense of touch, which thus leads to a significant increase in productivity [5]. Commercial applications of haptics are cellular devices with touch-screen technology (Nokia, Motorola), personal computers (Mac book, Mac bookPro), arcade video games with distant joysticks (Sony), servo systems in large aircrafts. Haptic feedback is also the key to medical interventions, for example when an anaesthetist inserts an epidural needle, a surgeon makes an incision, a dental surgeon drills into a carious lesion or performs microsurgeries [6]. The potential of haptics in the field of medical procedures and acquisition of clinical skills is great and they will affect the medical profession at large.

Understanding the Technology

Psychomotor skill acquisition research dictates that any movement in the body is initiated by a motor program to the appropriate musculature via a series of commands. These commands identify the muscles which have to be contracted and define the nature of the movement. Once the program is selected, it is run off, and it results in the movement of that muscle [5]. Schmidt suggested that in order for the program to be run, the operator must supply the parameters of the proposed movement, such as duration, speed, force, and movement size. When these parameters are plugged into the general program, an appropriate movement can be made. Performers play a central role in the control of movements.

Haptics are enabled by actuators. Actuators are devices that apply forces for touch feedback, and controllers. Whenever an electrical stimulus is applied, there is mechanical motion in the actuator. Earlier, only electromagnetic technology was used. These electromagnetic motors typically operate at resonance and they provide strong feedback, but produce a limited range of sensations. Newer generations of actuator technologies are emerging, with more rapid response times, which include electroactive polymers, piezoelectric, electrostatic and subsonic audio wave surface actuations [Table/Fig-2]. This mechanical stimulation can be used to assist in the creation of virtual objects in a computer simulation, to control such virtual objects, and to enhance the remote control of machines and devices, thus providing visual and tactile information to the operator in real time [8]. In the fields of medicine and surgery, adding robotic precision to the skill of a clinician by obtaining real time information ensures patient safety, procedural success rate, as well as it facilitates medical and dental training [9].

Haptics, A Key to Medical Interventions

Medicine, from its inception, has been about connecting clinicians with patients through the sense of touch. Technology has changed the way medical practitioners interact with their patients. As technology evolves medical solutions, the opportunity for haptics grows. The use of simulation has been proposed as the next major step in the evolution of health science education [4]. The growth of computer hardware and software has led to the development of

Haptic	Relating to the sense of touch
Proprioceptive	Relating to sensory information about the state of the body
Vestibular	Pertaining to the perception of head position, acceleration, and deceleration.
Kinesthetic	Meaning the feeling of motion. Relating to sensations originating in muscles, tendons and joints
Cutaneous	Pertaining to the skin itself or the skin as a sense organ. Includes sensation of pressure, temperature, and pain
Tactile	Pertaining to the cutaneous sense but more specifically the sensation of pressure rather than temperature or pain
Force Feedback	Relating to the mechanical production of information sensed by the human kinesthetic system

[Table/Fig-1]: Definitions of main terms used when describing haptics and the sense of touch [7]

First	Actuators work on electromagnetic principle Early haptic response systems typically vibrated the whole device with in limited range .
Second	Actuators work on electromagnetic principle Micro Chips are used that enable location specific responses to be created.
Third	No actuators required. A weak current is sent from a device on the user The oscillating electric field around the skin on their finger tips creates a variable sensation of friction depending on the shape, frequency, and amplitude of the signal. (Reverse-Electrovibration) [6].

[Table/Fig-2]: Generations of haptics [10]

virtual worlds that support the field of advanced simulation. Virtual reality allows users to move in the created virtual world in a way which is similar that of moving around to real life. Three-dimensional haptic technology of VR has only been recently proposed as a powerful tool for the education of health professionals. There are critical benefits in the medical space, including.

Tactile Knowledge: Haptics provides immediate and intuitive tactile feedback of relevant information to the users. Enhancement of Performance: Relevant feedback is delivered at the "right time", which thus helps in avoiding distraction and in minimizing ambiguity.

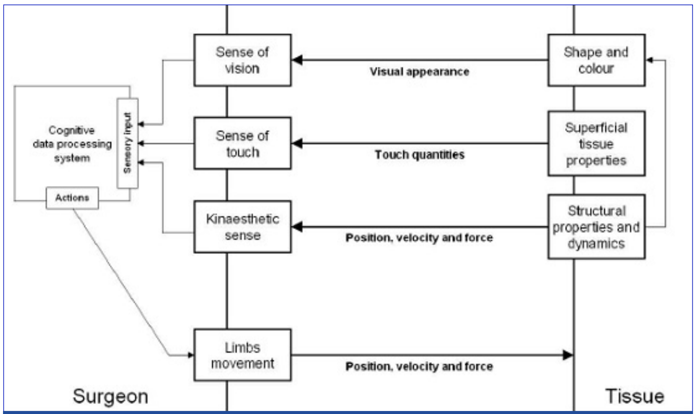
Intuitive Alerts: These assist users in prioritization of important information, multisensory experience, that helps in increasing clinical proficiency and in decreasing medical errors and costs [11].

Haptics and Clinical Skill Acquisition

a. Haptics in medical and dental examinations: This includes characterization of the nature of haptic information, and its perception, e.g. haptic endoscopy [12] laparoscopy [13], sigmoidoscopy, bronchoscopy.

b. Haptics in training and evaluating clinical skills: Students traditionally devote several years to the acquisition of sufficient fine motor skills, for their preparation. Recently, haptic simulators have been introduced into the medical curriculum to address growing need of effective training and evaluation of clinical skills. Such simulators can be applied in a wide variety of medical professions and disciplines, including surgery, interventional radiology, anaesthesiology, dentistry, veterinary medicine, and the allied health professions. This technology has significant potential to complement traditional training approaches, especially in the fields in which hands-on training is not applicable or is as ethical as in dentistry. In most medical fields, plastic models have long been used as a traditional method of training. Thus, virtual reality system is a boon in the fields of medicine and dentistry e.g. virtual haptic back [14], shadow hand, periodontal training simulator (Periosim) [15,16], dental implant surgical simulators [17].

c. Haptics in the improvement of the performance of medical interventions: Current trends in interventional medicine remove direct contact between the patients and clinicians. Bilateral teleoperators and "smart" instruments that use tactile sensing/



[Table/Fig-3]: Haptic scheme for medical intervention

display devices, sensory substitution systems and other methods to enhance haptic feedback to a clinician should improve the performance of interventions, e.g interventional radiology [18], remote surgeries [19], [Table/Fig-3].

Haptics in Laproscopic and Endoscopic Surgeries

Haptic feedback in surgery, as an intraoperative, non-invasive, real-time diagnostic tool, turns out to be versatile [13].

- Instrumentation which provides artificial tactile feedback promises to be an optional intra-operative diagnostic tool.
- Due to its versatility, it may be used in any surgical situation in which the surgeon may require deeper assessment of tissue structures.
- Foreign body recognition, including shape and dimensions.
- Detection of arterial pulsation Tissue feature evaluation e.g elasticity, kinematics , pathological status.

It is known that in surgery, sensoric stimuli are best felt through bare hands, followed by conventional surgical instruments, and lastly, by endoscopic instruments [20,21]. The amount of sensitivity loss which is measured when using endoscopic instrumentation instead of bare fingers, varies between a factor of 8–20 [20]. The main cause of disturbance of haptic sensations is frictional forces [22]. Frictional forces are forces which are caused by the friction between the instruments and the trocar. Frictional force may be reduced when the mechanical efficiency of the endoscopic instrument is enhanced, for instance, by lubricating the shaft of the instrument. As a result, the amount of haptic feedback may be enhanced [21]. It seems that by combining several factors, such as visual feedback, haptic feedback, and endoscopic experience, performances of certain surgical tasks can be improved [23]. Video analysis of endoscopic procedures showed tissue slippage which occurred during grasping actions, which resulted in tissue damage, when haptic feedback was absent [24,25]. The concept is indeed promising. Surgeons could possibly benefit from additional feedback, but there is still much to learn about the specifics and advantages of included force feedback when it comes to prevention of surgical errors.

Haptics for Neurosurgery Simulation [26]

Convergence of political, economic, and social forces has limited, neurosurgical, resident operative exposures. There is a need to develop realistic neurosurgical simulations that reproduce the operative experience, which is unrestricted by time and patient safety constraints. A computer-based, virtual reality platform offers simulated resistance and relaxation, with passage of a virtual three-dimensional ventriculostomy catheter through the brain parenchyma into the ventricle. A dynamic, three-dimensional, graphical interface renders a changing visual perspective, as the user's head moves, e.g. Second Generation Haptic Ventriculostomy Simulator Using the ImmersiveTouch™ System.

Surgical Simulation System for Cleft Lip Planning and Repair

This system allows the user to interact with a virtual patient to perform the traditional steps of cleft-lip repair. The system interfaces to force-feedback (haptic) devices to track the user's motion and to provide feedback during the procedure, while performing real-time soft-tissue simulation. The user is prompted to select anatomical landmarks on the patient data for preoperative planning purposes and then their locations are compared against those of a "gold standard" and a score which is derived from their deviations from that standard and time which are required, is generated [27]. The user can then move a haptic stylus and guide the motion of the virtual cutting tool. The soft tissues can thus be incised by using this virtual cutting tool, which is moved by using virtual forceps, and they can be fused, in order to perform any of the major procedures for cleft-lip repair.Simulator is a valuable training tool which provides residents with a means to practise anatomical identification for cleft lip surgery without the risks which are associated with training on a live patient. Educators can also use the simulator to examine as to which markers are consistently problematic, and modify their training to address these needs e.g Bio Digital system cleft lip palate virtual simulator – Smile train 3-D real time simulator [28].

Robotic Arm

According to the Robot Institute of America, "A robot is a reprogrammable, multifunctional manipulator which is designed to move materials, parts, tools or specialized devices through variable programmed motions, for the performance of a variety of tasks". This interaction of robot with environment is commonly accomplished by using some sort of arm and gripping device or end effectors. The robotic arm has a few joints which are similar to those of a human arm, in addition to shoulder, elbow, and wrist, coupled with the finger joints [29].

Haptic Robot arm is used for various applications,

- To lift heavier objects.
- To lift nuclear wastes without harming humans.
- To use as external limbs of a surgeon during complex retinal or heart surgeries.
- To use as prototype for a Bomb disposal robot.

Needle Simulation

This is an important topic and it has several applications in clinical procedures, e.g., biopsies, injections, neurosurgery, brachy therapy cancer treatment, spinal anaesthesia and regional anaesthesia. Training opportunities are limited and there is a lack of available, virtual reality-based (VR) simulators. The first anaesthesia simulator, SIM1, was described in 1969, and the progress made in computer technology led to the development of different systems, including high-fidelity simulators [30]. However, the limited numbers of virtual reality (VR)-based simulators for RA, narrow their use for training purposes. Needle simulation requires profound theoretical knowledge and repeated performances to gain sufficient manual skills for successful accomplishment of such procedures. Although there is widespread utilization of simulators for learning and improving medical skills in general and sophisticated full-scale simulators for general anaesthesia, the use of such mannequins for RA and spinal anaesthesia is limited, e.g. Chiba needles for haptic rendering. According to the Haptics Optional Surgical Training System (HOSTS) which is developed for the US Army, a training system has to fulfil several criteria These include:

- Identification of the right injection site and proper injection angle.
- keeping the hand position at the proper angle and stably during the injection, which requires knowledge of the appropriate hand position for each block position and proper needle placement during injection.
- Ensuring that a nerve is not pierced and featuring the ability to assess nerve stimulation.

Haptic Interaction with 3D Ultrasound Data

Touch Your Baby Before He or She is Born. This system is being currently targeted for use in pre-natal imaging Parents are able to interactively feel as well as see three-dimensional imagery of the child. This has several important benefits. First of all, it allows physicians to more clearly explain the developmental process, progress of growth of foetus to parents- to- be and any existent complications. Secondly, it helps in easing parental stress and anxiety over the progress of their child. Finally, it helps the all-important parent-child bonding process. The system can further be refined in order to be used for medical diagnosis, surgical planning, and intraoperative procedures, E.g. The e-Touch sono™ system [31].

Haptic Back [11]

Training is typically done in laboratory settings, in which students work on each other with teacher-student ratios, that make it difficult for students to get the levels of feedback that they desire, as to whether they are feeling what they are supposed to be feeling. These settings also seldom provide the ranges of ages and conditions which are typical of patient populations that the students will eventually be treating.The development of the virtual haptic back (VHB) was undertaken to address these limitations. It is a simulation of the contours and the tissue textures of human backs and is presented to users both haptically and graphically, i.e., by feeling and by sight. The simulation is based on measurements of real backs, with the contours being captured by 3D photography and the tissue texture being measured as tissue compliance (the inverse of stiffness). e.g. PHANToM 3.0 haptic interface (SensAble Technologies, Woburn, MA).

Haptic Surgical Correction of Dento-Facial Deformities [32]

Research is focused on conducting projects to improve the diagnosis and management of dentofacial deformities. Applying the recent advances in stereophotogrammetry, haptics, enables us to Establish 3D facial characteristics of non-deformed faces. Study the 3D soft tissue changes in response to several skeletal orthognathic procedures.

- Assess the accuracy of prediction planning in orthognathic surgeries.
- Build a mathematical model to measure facial scarring.

Haptic Suturing Simulator

This simulator incorporates several interesting components such as real-time modeling of deformable skin, tissue and suture material and real-time recording of state of activity during performance of the task by using a finite state model. Actual needle holders are attached to the haptic device, as the graphics of the haemostats, needles, sutures, and virtual skin are displayed and updated in real-time. But a somewhat realistic, tactile force feedback is provided to the learner. Ongoing development is focused upon providing users with a more accurate force feedback, a scoring mechanism, and added instructional functions. The goal is to provide an efficient method to learn the suturing procedure by measuring surgical skills in a simulator [33].

Robot Assisted Surgery

These systems are teleoperated with the surgeon at a console, controlling a `joystick' and with the instruments being manipulated by robotic arms inside the patient [34], e.g. Da Vinci'-system produced by Intuitive Surgicals.

Figure: Schematic overview of a telesurgical system. Some advantages of robotic telemanipulation [35].

Limited dexterity is restored, as the surgeon no longer has to move the instruments. This can be done via a foot pedal which is used to freeze the instruments.

- Surgeon can sit in a comfortable position and make a robotic.
- Visualization is improved, and it can even be three-dimensional.
- There is 'tremor eradication.

The main limitation of current technology of robot assisted surgery is reduced number of degrees of freedom, which results in low manipulability of the surgical instruments, no force or tactile feedback, absence of a natural interface and the robotic hardware being expensive [36].

Haptics in Dentistry

Even though use of complex and realistic medical simulators is becoming more and more common in medical education, the use of simulators in the field of dentistry has not been well exploited as yet. Dental simulators provide an efficient means to quickly teach preclinical dental students dental procedures, while increasing their hand-skills considerably. Repetitive procedures such as proper hand and instrument usage and placement are primary targets which have to be learned on dental simulators [37]. Two kinds of dental simulators are currently available: manikin-based simulators that provide a physical model of the patient's head and mouth, on which certain dental procedures can be performed by using real dental instruments e.g DentSim™, which is developed by [DenX Ltd], Image Guided Implantology (IGI) which is also developed by DenX, Ltd and haptics based simulators that employ a PHANToM™ haptic device [SensAble Technologies, Inc.] and virtual models of a human tooth or mouth as a platform for facilitating dental practices e.g Virtual Reality Dental Training System (VRDTS) [Novint Technologies], Iowa Dental Surgical Simulator [IDSS] [38]. Instead of using real dental instruments, the trainee holds the haptic device stylus to manipulate a set of virtual instruments that are shown on a monitor screen. The tactile feedback reproduces clinical sensations in the hand of the operator who is using dental instruments.

Challenges Associated with Haptic Technology

Integrating haptics poses technical challenges on all fronts: haptic interface hardware design, tissue and organ model development, tool–tissue interactions, real-time graphical and haptic rendering, and haptic recording and playback [38,39].

*Haptic Devices Design

One of the constant challenges associated with integration of haptics into virtual environments is the need for haptic interface devices with the requisite DOF, range, resolution, and frequency bandwidth, both in terms of forces and displacement. With current technology, it is hard to imagine using a single universal device for all medical procedures, and it is likely that groups of similar medical procedures can be simulated with specific devices [Table/ Fig-4-6].

*Tool–Tissue Interaction

Interaction between instrument and an organ occur during a surgery. Realistic visual and haptic rendering of tissue cutting, bleeding, and coagulation are important components of a surgical simulator. The physics of the dynamic phenomena which underlie surgical cutting or tearing of soft tissues is extraordinarily complex. Accurately modeling the interactions between the sharp edge of a tool and the soft tissue has been proven to be rather difficult.

*Organ models

In vivo tissue mechanics are critical for measuring material parameters which are needed for realistic simulations. In addition, current organ-force models are linear, homogeneous, and isotropic. Such models are inadequate for representing the inherent nonlinearities, anisotropy, and rate dependence of soft tissues. Complex tissue models, on the other hand, are computationally expensive. The accuracy requirements of organ models must also be investigated from the perspective of human haptic perceptions. Constructing a multilayered computational architecture is highly useful.

*Real-Time Rendering

The number of computations which are required for real-time visual and haptic rendering of organ-force models is another bottleneck in our simulations.

***Haptic recording and playback:** Also important are the benefits of using the same haptic device to simultaneously record and display haptic stimuli for MISST. Although considerable interest in haptic display of compliant objects for MISST exists, the haptic recording and playback concepts require further exploration.

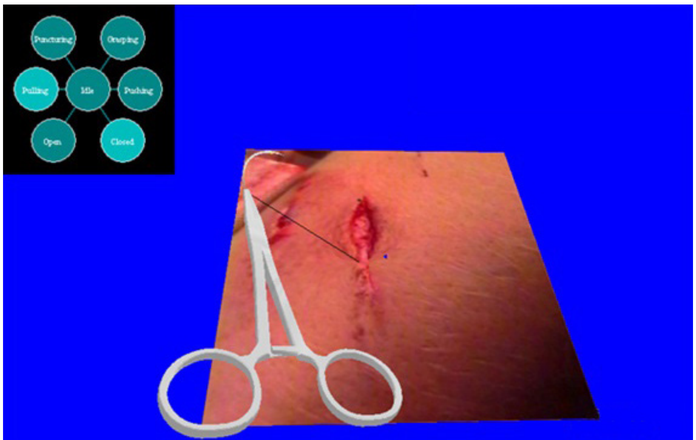
Future Applications of Haptics

Future applications of haptic technology cover a wide spectrum of human interactions with technology. Some other applications

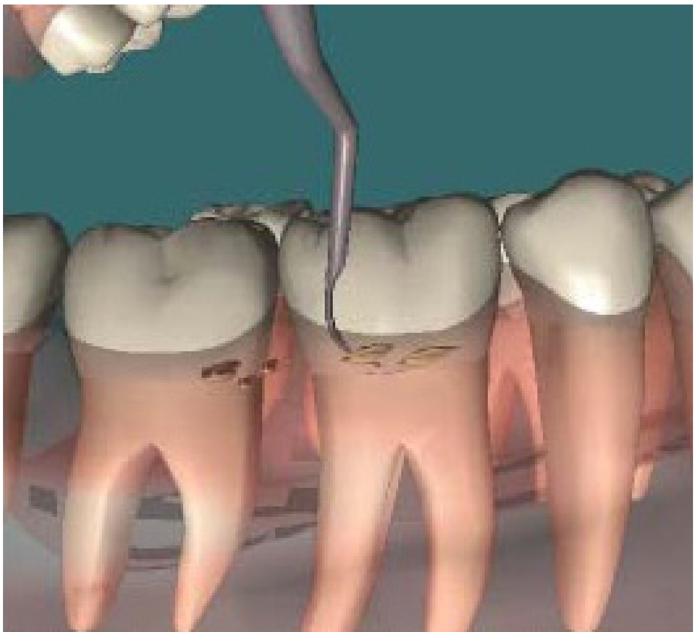
Lanfranco et al., [40]	Haptic feedback is decreased in conventional endoscopic surgery
Picod G [22]	The forces of interaction between organs and instrument tips during endoscopic gestures range from 0.1–10 N
Thole G [24]	Haptic feedback is best felt through: 1. Bare hands 2. Instruments for open surgery. 3.endoscopic instruments
Lemole GM [26]	Haptic feedback offers simulated resistance and relaxation with passage of a virtual three-dimensional ventriculostomy catheter through the brain parenchyma into the ventricle.
Cristian Luciano [26]	During the experiment, medical students improved their performance from 10%-50% to 100% in fewer than 30 trials showing the potential of the ventriculostomy simulator.
Strauss G [41]	VSR systems have the potential to revolutionize surgical training. All surgical experienced probands evaluated the VSR-scenario as near-to-reality.
Montgomery K, [42]	The simulator is a valuable training tool, giving residents a way to practice anatomical identification for cleft lip surgery without the risks associated with training on a live patient. Educators can also use the simulator to examine which markers are consistently problematic, and modify their training to address these needs.
Schendils [43]	Soft tissue deformation of the haptic mesh realistically simulates normal tissues when haptic-rate (>1 kHz) force-feedback is provided.
Rama Krishna [44]	A robotic arm with four degrees of freedom designed is able to pick the objects with a specific weight and place them in a desired location. To facilitate the lifting of the objects, Servomotors with a torque of 11 kg are used. Haptic Robot arm is used for various applications, of them few are as follows: To lift heavier objects To lift nuclear wastes without harming the humans Used as external limbs of a surgeon during a complex retinal or heart surgeries Prototype for a Bomb disposal robot
O. Grottke [45]	Technically, VR simulators do not consider individual patients' anatomy and cannot be adapted to different regions such as the inguinal region, spine, neck, or arm.
Amir M [46]	Pilot human factor studies have demonstrated the significant potential for scientific and commercial applications of HUTS {haptic ultrasound training system). The system is portable, inexpensive and is able to demonstrate US reslicing together with other reg.istered imaging modalities simultaneously

Gottlieb R [47]	Faculty perceptions of VRS students' abilities were higher than for non-VRS students for most abilities examined. Since ergonomic development and technical performance were positively impacted by VRS training, the results support the use of VRS in a preclinical dental curriculum.
Jasinevicius TR, [48]	Compared the efficacy of a virtual reality computer-assisted simulation system (VR) with a contemporary non-computer-assisted simulation system (CS). Faculty spent 44.3 hours "interacting" with twenty-eight students, averaging 0.5 hours per VR student and 2.8 hours per CS student. Thus, CS students received five times more instructional time from faculty than did VR students.
Lackey MA [49]	This study completed its first year of student experience using 40 DentSim simulators, in conjunction with an 80-unit traditional simulation laboratory. The results of the first-year experience were encouraging, although certain areas proved problematic and frustrating for both students and staff.
Suvinen TI [50]	Student response to teaching and learning in the simulator over a 3-year evaluation period, collected via a student questionnaire was uniformly positive. Students were very enthusiastic about the learning environment and educational approach, preferring it to traditional preclinical laboratory instruction

[Table/Fig-4]: Review of studies for haptic in medicine



[Table/Fig-5]: Haptic suturing



[Table/Fig-6]: Calculi being removed with haptic scaler

are Virtual Reality interfaces used for an internet shopping mall (remotely touching materials like clothes via the internet, CAD or other tangible spaces). Research focuses on the mastery of tactile interactions with distant objects, which if successful, may result in applications and advancements in gaming, movies, manufacturing, medical, and other industries. The medical industry stands to gain from virtual and telepresence surgeries, which provide new options for medical care One currently developing medical innovation is a central workstation which is used by surgeons for performing operations remotely. Local nursing staff set up the machine and prepare the patient, and rather than travelling to an operating room, the surgeon becomes only a telepresence [15]. This allows expert surgeons to operate from across the country, thus increasing availability of expert medical care. It is a useful tool for simulating surgery for training purposes. Haptic technology aids in the simulation by creating a realistic environment of touch. Yet, current trends in medical technology and training methods involve less haptic feedback to clinicians and trainees.Performances of experts and novices can be modelled by using artificial intelligence techniques, in order to provide immediate constructive feedback to trainees during clinical skill practice.

CONCLUSION

In the future, robots and intelligent machines should adapt themselves autonomously to the open environment, in order to realize physical support that they provide for human activities. Advanced technology simulation is on the verge of dramatically affecting health care education. Specifically, virtual reality-based technology allows a more advanced simulation, thereby setting new state-of-the-art medical and dental simulations.The science and technology of haptics thus has great potential to affect the performance of medical procedures and learning of clinical skills.

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PARTICULARS OF CONTRIBUTORS:

1. Assistant Professor, Department of Periodontics and Implantology, SGT Dental College Gurgaon, Haryana, India.
2. Senior Lecturer, Department of Oral Medicine and Radiology, Kalka Dental College Hospital and Research Centre, Meerut, India.
3. Senior Consultant, Department of Dermatology, India.
4. Professor and H.O.D., Department of Periodontology, Noorul Islam College of Dental Sciences, India.
5. Senior lecturer, Department of Periodontics, Saraswati Dental College Hospital and Research Centre, Lucknow, India.

NAME, ADDRESS, E-MAIL ID OF THE CORRESPONDING AUTHOR:

Dr. Shalini Kapoor,
Assistant Professor, Department of Periodontics and Implantology, SGT Dental College Gurgaon, Haryana, India.
Phone: +91-9013290054, E-mail: dr_shalinibasur@yahoo.co.in

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