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Robot application in hip surgery – experiences and actual tasks in the design of a navigated mechatronic assistance system

Purpose:
The motivation of the research work described in this contribution is based on our conviction that the outcome of total hip replacement surgery in terms of highly reproducible, good results – concerning both, short term and long term results – can be improved by appropriate mechatronic assistance systems. The expected benefit will be particularly evident when using less invasive operating techniques. From the beginning of our work we have focussed on the design of an interactive system the application of which is completely different from the fully automatic operation of the first generation hip robots “Robodoc” and “CASPAR”.

Methods:
The design of our mechatronic assistance system started from the novel concept to integrate an optical navigation system and a robotic arm, combining the specific advantages of each of the two components. The integrated system offers precise positioning and guiding of surgical instruments according to pre-operative planning. A unique feature results from its capability to track small motions of the patient in real time, eliminating the need to rigidly fix the anatomical structure to be operated. The robot arm can be regarded as a controlled machine actuator of a navigation system. Its operation is mainly controlled by interactive operating modes which are based on a versatile haptic interface. The system supports the surgeon in those parts of a procedure where human skills are limited, but always lets him take full control, for example by directly grasping and moving the arm at its wrist if he wants to push the arm aside.
Compared to manual instrument guidance, even if the instrument is tracked by a navigation system, the stable tool guidance of the mechatronic system offers several additional advantages which are particularly valuable to support less or minimal invasive operating techniques.

- No problems due to tremor or unintentional slipping of the tool,
- excellent bone preparation by precise drilling and reaming,
- surgery will exactly and reproducible achieve pre-operatively planned targets,
- elimination of ergonomic problems, such as difficult hand-eye-coordination and frequent changes of viewing direction.

Results:
In 2002 and 2003 several clinical trials have been performed to demonstrate the technical and medical feasibility of the approach. Our mechatronic assistance system has been world’s first system to support the implantation of the acetabular cup in robot assisted hip surgery. The next steps have been concentrated on further developments in the following key areas.

- Improvements of the man-machine interface in order to make the operation of the system faster, easier, and more robust,
- extension of the system application also to the femoral part of total hip replacement, including support for resurfacing implants,
- investigation of novel tool systems for bone preparation and prosthesis implantation that fully exploit the advantages of mechatronic, slip-away-safe tool guidance,
- further improvements for less invasive operating techniques.

Conclusion:
It has turned out that apart from proving the basic system functionality it is a time consuming task to design all system components in a way that they are robust and easy to handle to be acceptable for daily clinical application. After a partial redesign of the system architecture presently the implementation of improved modules to support both the acetabular and the femoral part in total hip replacement surgery by the mechatronic assistance system is in progress.