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Making Better Orthopedic Cutting Tools

Cutting Geometries and Styles

There is strong interest to improve the cutting performance of drills, reamers, and broaches.

Drills

Designing for greatly improved cutting performance in bone drills is a relatively new area of activity for orthopedic product development engineers. Until recently, most cutting instrument designs were based upon principles and theory established for the metal cutting and wood working industries. Substantial efforts are now being expended to verify how much of this conventional wisdom actually applies to cutting bone. Empirical testing is showing that changing the many variables of a drill can yield significant improvements.

One recent innovation is the "turbo" tip drill, shown in Figure 1 below. The drill has no central tip, having instead two offset facets, thus eliminating the point on the drill where the Surface Cutting Speed is zero. Drills with this tip configuration cut more efficiently (faster with less heat generation) than the same design drill with a conventional tip. The performance is far superior to those with the popular brad point tip, with the trade of being the lack of the centering and alignment afforded by the brad.

Figure 1. Turbo Tip Drill

Reamers

Reamers have fared better receiving more attention, and benefiting from many more years of R&D development. Significant efforts have recently been devoted toward perfecting designs that cut bone more efficiently and facilitate debris capture and removal from the cutting zone. Sample of some of the numerous existing styles are shown in Figure 2 below.

Figure 2. Flute geometries

Reamer design is a compromise between cutting performance, ease of use, and debris removal. Straight flute reamers tend to chatter more than those with helical spirals. Spiral flute styles with left-handed flutes (and right sided cutting geometries) tend to pull into the bone, but debris flows up the flutes better. Reamers with right-handed flutes do not pull into the cut, but tend to pack the bone debris into the cutting zone more.

Broaches

Broaches have also benefited from a renaissance in design innovation. Facilitated by advances in machine tool technology, grinding machines are now able to produce elaborate and sophisticated tooth patterns on complex broach forms. One popular pattern is the "diamond tooth", shown in Figure 3.

Figure 3. Diamond Tooth Pattern

The diamond tooth is not a new pattern, but rather one that has been for many years (and still is) produced by hand grinding! However, modern six-axis grinders with advanced CNC controllers greatly improve the performance of the new generation of diamond broach tooth patterns by adding consistency and precision to far more aggressive tooth geometries. This has translated into more efficient cutting, and reduced OR time in the preparation of the femur to receive the implant. Other conventional patterns that also benefit from advances in machine tool technology are shown in Figure 4.

Figure 4, picture of several other modern broach tooth patterns

Standard annular tooth patterns like those on the broach on the far left directly resist the insertion of the broach and therefore give a feel of being much more difficult to drive into the bone. The diamond tooth broach on the far right cuts at an angle to the insertion of the broach. This pattern offers less resistance to the driving force. This changing of angles in the diamond pattern and reduction in resultant force vectors changes the tactile feedback experienced by the user and gives the appearance that it cuts better. The resultant envelope of the diamond tooth is more accurate as well since an annular broach leaves steps in the bone where each tooth ends. The diamond tooth pattern alternates the cutting surfaces so the steps are smaller and never circumferential. Whatever the real, or perceived, benefits both styles have their champions.

Many of the newer grinders can vary tooth spacing and pitch to accommodate specific cutting needs in specific areas (i.e. smaller teeth distally where less material is removed and where a deeper cut may weaken the rasp). This is a technology enhancement that will improve all broaches.

Technology

Another machine tool advance that helps generate new and improved instrumentation designs is the wheel pack change capability found in several new grinding machines. This feature offers the ability to more easily add additional cutting facets, blood grooves, cutting gashes, and secondary cutting edges during the initial production set-up, thus significantly reducing set-up cost and improving the accuracy of secondary features to the primary flute geometry.

Grinding vs. Milling

Broaches and reamers produced for orthopedic applications that are ground offer three significant benefits over those produced by milling.

Sharpness

Both grinding and milling processes remove metal by 'shearing' it from the surface. A milling cutter operates with relatively few cutting edges, while a grinding wheel has thousands of discrete cutting edges. Microscopically, milled surfaces present an endless landscape of ragged edges, with tears, sub-surface cracks and crevices that are analogous to viewing a coral reef. Conversely, ground surfaces look, more analogous to a sandy seabed.

Most important and very relevant to cutting performance a ground cutting edge is significantly sharper than one produced by milling. Even cutting geometries initially produced by milling and subsequently sharpened by grinding are inferior to those produced solely by grinding. This is because ground surfaces have significantly better surface integrity than milled surfaces. Surface integrity considers all aspects of the surface from its finish to the sub-surface microstructure.

Figure 5; Close-up photos of a milled vs. ground broach or reamer

The superior surface integrity is important for two reasons. First, the smoother ground surface offers less frictional resistance to bone debris generated at the cutting interface sliding over the flute. This results in less heat generation and therefore reduces the possibility of subsequent bone necrosis.

Second, the superior surface integrity of a ground instrument also provides fewer opportunities for micro-bacteriological growth sites. While no studies have been identified that compare the relative cleanability of both types of surfaces, it is intuitively obvious that ground surfaces are easier to clean and sterilize.

Coatings on Broaches and Reamers

Utilization

Coatings are being applied to surgical cutting tools more and more frequently. Coatings may cover either all or part of the cutting geometry, depending upon whether the purpose is to denote specific measurements or to associate components of a particular instrument, such as a handle with a broach. Often, entire sets of broaches and reamers are coated identically in order to differentiate them from other sets that might have the same general appearance but have, say, different hip neck offsets. Figure 5 shows two popular coatings—Aluminum Titanium Nitride (AlTiN), and Titanium Nitride (TiN) and, with an uncoated broach in the middle.

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Figure 6; Coated broaches

Benefits

In general, most coatings provide only marginal benefit relative to cutting performance; their use is primarily for identification or differentiation (i.e., between sizes or particular applications) from other instruments in a system. This is because the surface cutting speeds in orthopedic surgical applications are slow compared to those used to machine metal for which several of the coatings were developed. However some modern cutting tool coatings do offer improvements in cutting performance, especially in relatively hard and abrasive cancellous bone. Coatings such as TiN, AlTiN, and CrN can improve "sharp edge retention", lower surface friction, and improve chip-packing resistance

Coatings are frequently used to enable visual association of an instrument feature with a written surgical protocol. For example: "push buttons" are plated with hard gold plating; caps are TiN coated; and thumbscrews are anodized.

Marketing executives want their company's instruments to "sizzle." However, the reality is that most coatings do not make broaches or reamers cut significantly better, rather they may reduce the cutting action. This is particularly true of anodic coatings, where the electrical potential is highest at a sharp edge causing build-up, and less true for deposited coatings, especially those done in a vacuum.

LFCr.

One type coating does offer a significant degree of improvement in terms of cutting efficiency and product durability and longevity. Low Friction Chrome (LFCr) is a conformal chemical coating that increases surface lubricity of the base metal of a broach or reamer. This lowers the surface friction of bone moving over the cutting instrument and reduces heat generated at the cutting surface interface in the same fashion as grinding (above), again helping to minimize the potential for bone necrosis. LFCr provides a durable surface that maintains the cutting edge for a considerably longer period of time than uncoated stainless steel.

LFCr helps maintain a "like new" appearance on stainless steels that might otherwise appear dull and lusterless after repeated cleanings and autoclaving. Uncoated instruments made from stainless steel are very susceptible to watermarks from cleaning and surface abrasion. 17-4 PH steel is normally only hardened to 40 Rc range. LFCr coated instruments resist water spotting, and the surface harness is over 65 Rc. They are very abrasion resistant. Also, LFCr's more 'cleanable' surface enhances the visibility and durability of laser marking.

Some limitations of LFCr are cost, and the tendency for the coating to build up on sharp edges where the electrical potential is higher and material deposition is greatest. Cutting edges would tend to be duller compared to uncoated instruments when brand new. Coating with LFCr is also quite expensive, adding up to $5 on a typical reamer application. It also adds one to two weeks to the lead-time, as most manufacturers do not have in-house coating capability. It is however less expensive than the Plasma Vacuum Deposition such as TiN and AlTiN, but these coatings offer the benefits of different colors, in this case Gold and Black.

Summary

Orthopedic manufacturers are always striving to differentiate themselves from one another. As implant designs and materials become fully evolved it becomes harder to tell one company's offerings from another. One way to achieve a positive differentiation is with instrumentation. Elegant and stylish designs are important, they need to "sizzle", but they also need to work well. In cutting tools modern machine tool technology is helping designers to achieve significant improvements with classical designs, as well as enabling them to produce radically new ones.