Editorial copy included in BoneZone magazine regarding gundrilling in the medical field.

Gundrilling:

Should We Do It Ourselves?

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Introduction
Used to make gun barrels more than 100 years ago, gundrilling is the process of boring long or deep holes. Back then, it was a particularly time consuming and costly manufacturing process. Today, gundrilling is a reliable high-production method used to create both long *and* short holes. However, it is still regarded as a "black art" process that is *best left to the experts*. This should not be the case.

Gundrilling is commonly employed for the production of cannulated intramedullary devices as nails, screws and cannulated
instruments, such as drills. Gundrilling provides very straight holes with extremely close tolerance and excellent surface finish in diameters as small as .040" (1mm).

Gundrills
A gundrill consists of a hollow carbon steel tube with a V-shaped groove or flute along its length, and a carbide cutting tip ground with a similar flute. The tip contains a hole below the cutting edge that aligns with the hole in the tube. The hole allows cutting oil to pass at high pressure through the shank and over the tip to lubricate, cool and flush chips back along the V flute.

The drill point is eccentric at generally one quarter of the diameter. The net result is a tool that, due to cutting forces, wants to move its eccentric point to the hole center, but is prevented from doing so by the remainder of the tip diameter. This side pressure is absorbed by a support or wear pad that rubs and burnishes the hole, effectively creating its own guide bushing as it drills. Once set on its path, the drill locks itself into a direction and follows it without deviation.
The resultant hole is virtually identical to the size of the drill used and yields a fine burnished finish and a hole with practically zero deviation from its drill path.

The drill bushing is critical. It supports the drill so that it can start to cut, considering the eccentric point, and controls the initial path of the drill. It must be set to tolerances of "gundrilling standards," typically drill diameter -0/+.0002". Any more tolerance and the drill could easily deviate, giving greater runout and, in severe cases, premature drill wear and breakage. The drill bush should always make physical contact with the work face ensuring maximum possible support of the drill, avoiding both leakage of the high-pressure coolant and also chip entrapment. All coolant and chips must pass back along the drill flute.

The single or multiple drilling spindles and slides are horizontally mounted with fixed worktables. Parts may be fixtured between a part counter rotation driven chuck and tailstock with a pneumatic advance/retract rotating female support cone. Both variable spindle speed motors and feed drive servos are PLC-controlled with programmable operator interfaces.

Critical to a gundrilling machine's performance is its initial build quality. This precursor to success is not always understood. Some users believe that a relatively simple process such as gundrilling demands little sophistication in the design and production of machinery—a belief with which this author strongly disagrees, arguing that compromise is unacceptable in relation to hole straightness and sizing, drill life and finish integrity.

There is no substitute for the provision of hardened box ways, hand-scraped surfaces and laborious alignment protocols in the production of precision high production machinery. Gundrilling machines must follow this discipline. Linear ways and milled wear surfaces, while perhaps acceptable for other types of manufacturing machinery, cannot provide equivalent long-term performance and reliability to the aforementioned build standards.

Set-up

In most applications, set-up consists of a spindle assembly driven by an AC servo and precision ball screw. An in-line chip box collects the returning cutting oil and chips as they are flushed back along the drill flute. The part is held by the chip box mounted part counter rotation drive and rotating tailstock support. The drill is held in the spindle, if necessary using a suitable drill driver adaptor, and the drill tip and shank pass through a drill bushing.

Whip guide assemblies are mounted between the spindle and rear of the chip box. They are employed to support long or extra long drill shanks and to minimize vibration. They will also travel along the slide being collected by the carriage as it advances and being dragged back to home position at the end of the cycle. In most applications, the whip guide inserts are made of molded polyurethane and either round holed or contoured to the drill cross section (usually for the rear of the chip box only). They will be a good fit to the drill shank and rotate in bearings to avoid drag.

It is generally accepted that a whip guide support is required for up to every 40:1 length to diameter ratio of unsupported length between spindle and chip box.

Example: for a drill diameter of 10mm and an unsupported length of 500mm. 500/10 = 50:1= 1 x whip guide will be needed.

Chip Removal

Chips must be removed at a rate equal to or greater than that at which they are being produced. To do so, the cutting edges and bearing pad must be lubricated and cooled. High-pressure coolant is introduced into the center of the drill tube through the spindle of the gundrilling machine to help break and evacuate the chips along the V groove of the tool and out of the hole.

The coolant, usually mineral oil, travels through the tubular drill shank, through the hole in the tip, and flushes the chips back along the drill flute and into a catchment area known as a *chip box*. If a "balanced condition" exists—whereby chips are being flushed and removed freely and steadily—then drilling is continuous and uninterrupted until completion.

The Drilling Operation

The drill is set up in the spindle and supported by the traveling whip guide and rear chip box whip guide. The correct drill bushing is installed and lies in contact with the work piece, which, in turn, is mounted in the counter rotation chuck and tailstock support. Parameters are programmed into the machine control. Primary considerations include spindle speed, feed or penetration rate and coolant pressure/flow.

Spindle speed - The optimal speed is determined mostly by the amount of heat generation at the cutting edge. *Overspeed* is often evidenced by chip discoloration, but primarily by the wear rate of the outer corner of the tool. Other contributory factors to the actual cutting speed include the hardness and structure of material being cut; coolant type, pressure and flow;

the grade of carbide and quality of the gundrilling tool; and the primal quality and current condition of the machine itself.

Feed (penetration) rate - The optimum feed rate is that needed to form a controllable chip while balancing the wear rate of the
drill's cutting edges. Too slow, and edges may "rub" work, hardening the face of the material. Too fast, and the cutting force may twist the drill shank and cause vibration, shocking the tip. Penetration rates vary from .375 to 4.000 IPM in the alloys mentioned in Exhibit 6, subject to material condition and hardness.

Coolant pressure/flow - Unlike less critical machining processes such as conventional drilling and turning, in gundrilling
operations, the coolant must achieve three objectives: cool, remove chips as fast and as efficiently as possible, and lubricate the cutting edges and the support or wear pads on the drill periphery. (This latter factor is often overlooked and may result in friction, overheating, poor finish, premature drill wear and potential breakage.)

Lubricants
Gundrilling oils should be selected with the greatest care. They must offer high lubricity with extreme pressure additives to withstand the burnishing action of the wear pads. To maximize tool life, avoid the use of soluble oils unless absolutely necessary, as they invariably do not have the same lubrication capability as these specialist oils. However, consideration may need to be given to soluble oils if oil additives such as chlorine are unacceptable.

Oil Temperature
Overheating causes denaturing of the oil, consequential deterioration of hole quality, and potential tool breakage.
Generally, air coolers or water-type heat exchangers are fitted to coolant systems as standard. Where environments experience high ambient temperatures and have no plant cooling water, then refrigerated cooling systems should be fitted.

Cutting Parameters
Primarily, metals employed in the manufacture of medical devices fall into one of three categories, none of which pose especially difficult challenges to the gundrilling process. Of the three types, titanium is the easiest to gundrill. Cutting parameters for these materials are indicated in the Exhibit below.

Material	Hardness Bhn	Cutting Speed SFM (SM/min	Penetration Rate IPM (mm/min)
15-5, 17-4PH	275-325	150 (46)	.700 (18) - .870 (22)
310, 316, 321 Series	135-185	210 (64)	1.500 (38) – 2.160 (55)
Ti-6AL-4V	320-380	100 (30)	.625 (16) - .750 (19)

- Precipitation hardening stainless steels - 15-5 PH, 17-4 PH
- Austenitic stainless steels - 310, 316, 320 Series
- Titanium - Ti-6Al-4V

Exhibit : Gundrilling Cutting Parameters for Typical Medical Device Materials

* Assumes free-cutting drawn material. Forged materials, in particular, will be up to 50% less.
** With rigid, well-aligned set-up and fixturing; regulated oil temperature of less than 100° F, this figure may be increased significantly. It is not unusual to drill at 1.2" (30mm).

Example: Knee Nail Ti-6Al-4V .213" diameter hole through x 15.787" (400mm) long = 15.787 divided by .800 = 19.7 min. drill time (conservatively), but possibly 15 minutes.

Benefits

Not only, as described, can gundrilling achieve the highest quality holes in terms of diameter tolerance and surface finish in a single drill pass, but a gundrilled hole can be almost "perfect" in terms of straightness. Deviation in concentricity to the outside diameter is a function of build quality, machine condition and set-up, as well as maintenance of consumable/wearable parts. It is generally accepted that hole straightness with a rotating drill will be within .001"/1" (0.1mm/100mm) total indicator reading (TIR). With counter rotation of the part, 50% of this value i.e. .0005"/1" (0.05mm/100mm) is achievable. This is a good working average, but considerably better results are obtainable with customer collaboration and "fine tuning" at the time of machine assembly and run off.

Conclusion

Gundrilling is often underappreciated as a simple, reliable, cost effective, in-house process. However, gundrilling is no longer a discipline beyond the comprehension or mastery of the OEM. The versatility of gundrilling machinery makes the process ideally suited for low as well as high volume production. With correct set-up, it is a matter of "pressing a button" and waiting until the hole is complete, even for considerable depths of 150 times drill diameter and beyond.

The type of component or device being produced obviously dictates the preferred drilling method; however, gundrilling is now an affordable consideration whose benefits are in reach of even smaller users that demand both quality and flexibility for the drilling of both long and short holes. As a rule-of-thumb, gundrilling proves faster than conventional or high performance. helical twin flute drilling when hole depth is in excess of ten times diameter, and yields unrivalled straightness, hole tolerance and surface finish.

With the benefits of today's technology, gundrilling is a realistic upgrade to the OEM tooling arsenal that can prove to be a cost effective alternative for meeting capacity requirements.