APEM journal
**Advances in Production Engineering & Management**
Volume 16 | Number 2 | June 2021 | pp 199–211
https://doi.org/10.14743/apem2021.2.394
**ISSN 1854-6250**
Journal home: apem-journal.org
Original scientific paper

# Bone drilling with internal gas cooling: Experimental and statistical investigation of the effect of cooling with $CO_2$ on reduction of temperature rise due to drill bit wear

**Shakouri, E.**[a, b,*], **Haghighi Hassanalideh, H.**[a], **Fotuhi, S.**[b]

[a]Faculty of Engineering, Islamic Azad University-Tehran North Branch, Tehran, Iran
[b]Iranian Tajhiz Sina, its. Co., Tehran, Iran

**A B S T R A C T**

Bone drilling is a major stage in immobilization of the fracture site. During bone drilling operations, the temperature may exceed the allowable limit of 47 °C, causing irrecoverable damages of thermal necrosis and seriously threatening the fracture treatment. One of the parameters affecting the temperature rise of the drilling site is the frequency of applying the drill bit and its extent of wear. The present study attempted to mitigate the effect of drill bit wear on the bone temperature rise through the internal gas cooling method via $CO_2$ and to reduce the risk of incidence of thermal necrosis. To this end, drilling tests were conducted at three rotational speeds 1000, 2000, and 3000 r·min$^{-1}$ in two states of without cooling and with internal gas cooling by $CO_2$ through an internal coolant carbide drill bit, along with six drill bit states (new, used 10, 20, 30, 40, and 50 times) on a bovine femur bone. The results indicated that in the internal gas cooling state, as the number of drill bit applications increased from the new state to more than 50 times, the temperature of the hole site increased on average by $\Delta T$ = 2-3 °C ($n$ = 1000 r·min$^{-1}$), $\Delta T$ = 5-8 °C ($n$ = 2000 r·min$^{-1}$), and $\Delta T$ = 5-7 °C ($n$ = 3000 r·min$^{-1}$). Furthermore, the internal gas cooling method was able to significantly reduce the effect of the drill bit wear on the temperature rise of the drilling site and to resolve the risk of incidence of thermal necrosis regardless of the process parameters for drilling operations.

**A R T I C L E I N F O**

*Keywords:*
Bone;
Drilling;
Thermal necrosis;
Tool wear;
Internal gas cooling

**Corresponding author:*
e_shakouri@iau-tnb.ac.ir
(Shakouri, E.)

*Article history:*
Received 15 March 2021
Revised 18 May 2021
Accepted 19 May 2021



## References

[1] Hillery, M.T., Shuaib, I. (1999). Temperature effects in the drilling of human and bovine bone, *Journal of Materials Processing Technology,* Vol. 92-93, 302-308, doi: 10.1016/S0924-0136(99)00155-7.

[2] Grzesik, W. (2010). *Podstawy skrawania materiałów konstrukcyjnych,* In Polish, WNT, Warsaw, Poland.

[3] Shakouri, E., Ghorbani, P., Pourheidari, P., Fotuhi, S. (2021). Resection of bone by sagittal saw: Investigation of effects of blade speed, feed rate, and irrigation on temperature rise, *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine,* Vol. 235, No. 6, 625-635, doi: 10.1177/0954411921999482.

[4] Karmani, S. (2006). The thermal properties of bone and the effects of surgical intervention, *Current Orthopaedics*, Vol. 20, No. 1, 52-58, doi: 10.1016/j.cuor.2005.09.011.

[5] Bachus, K.N., Rondina, M.T., Hutchinson, D.T. (2000). The effects of drilling force on cortical temperatures and their duration: An in vitro study, *Medical Engineering & Physics,* Vol. 22, No. 10, 685-691, doi: 10.1016/s1350-4533(01)00016-9.

[6] Henriques, F.C. (1947). Studies of thermal injury V. The predictability and the significance of thermally induced rate processes leading to irreversible epidermal injury, *Archives of Pathology,* Vol. 43, No. 5, 489-502.

[7] Davidson, S.R.H., James, D.F. (2003). Drilling in bone: Modeling heat generation and temperature distribution, *Journal of Biomechanical Engineering,* Vol. 125, No. 3, 305-314, doi: 10.1115/1.1535190.

[8] Allan, W., Williams, E.D., Kerawala, C.J. (2005). Effects of repeated drill use on temperature of bone during preparation for osteosynthesis self-tapping screws, *British Journal of Oral and Maxillofacial Surgery*, Vol. 43, No. 4, 314-319, doi: 10.1016/j.bjoms.2004.11.007.
[9] Gholampour, S., Shakouri, E., Deh, H.H.H. (2018). Effect of drilling direction and depth on thermal necrosis during tibia drilling: An in vitro study, *Technology and Health Care*, Vol. 26, No. 4, 687-697, doi: 10.3233/THC-181246.
[10] Shakouri, E., Mirfallah, P. (2019). Infrared thermography of high-speed grinding of bone in skull base neurosurgery, *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine,* Vol. 233, No. 6, 648-656, doi: 10.1177/0954411919845730.
[11] Cseke, A., Heinemann, R. (2018). The effects of cutting parameters on cutting forces and heat generation when drilling animal bone and biomechanical test materials, *Medical Engineering & Physics,* Vol. 51, 24-30, doi: 10.1016/j.medengphy.2017.10.009.
[12] Shakouri, E., Ghorbani Nezhad, M. (2020). An in vitro study of bone drilling: Infrared thermography and evaluation of thermal changes of bone and drill bit, *Physical and Engineering Sciences in Medicine,* Vol. 43, 247-257, doi: 10.1007/s13246-020-00842-x.
[13] Shakouri, E., Sadeghi, M.H., Maerefat, M., Shajari, S. (2014). Experimental and analytical investigation of the thermal necrosis in high speed drilling of bone, *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine,* Vol. 228, No. 4, 330-341, doi: 10.1177/0954411914524933.
[14] Udiljak, T., Ciglar, D., Skoric, S. (2007). Investigation into bone drilling and thermal bone necrosis, *Advances in Production Engineering & Management,* Vol. 2, No. 3, 103-112.
[15] Shakouri, E., Ghorbani Nezhad, M., Ghorbani, P., Khosravi-Nejad, F. (2020). Investigation of thermal aspects of high-speed drilling of bone by theoretical and experimental approaches, *Physical and Engineering Sciences in Medicine,* Vol. 43, 959-972, doi: 10.1007/s13246-020-00892-1.
[16] Shakouri, E., Sadeghi, M.H., Karafi, M.R., Maerefat, M., Farzin, M. (2015). An in vitro study of thermal necrosis in ultrasonic-assisted drilling of bone, *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine,* Vol. 229, No. 2, 137-149, doi: 10.1177/0954411915573064.
[17] Sun, Z., Wang, Y., Xu, K., Zhou, G., Liang, C., Qu, J. (2019). Experimental investigations of drilling temperature of high-energy ultrasonically assisted bone drilling, *Medical Engineering & Physics,* Vol. 65, 1-7, doi: 10.1016/j.medengphy.2018.12.019.
[18] Bai, X., Hou, S., Li, K., Qu, Y., Zhang, T. (2019). Experimental investigation of the temperature elevation in bone drilling using conventional and vibration-assisted methods, *Medical Engineering & Physics,* Vol. 69, 1-7, doi: 10.1016/j.medengphy.2019.06.010.
[19] Gupta, V., Pandey, P.M. (2018). An in-vitro study of cutting force and torque during rotary ultrasonic bone drilling, *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, Vol. 232, No. 9, 1549-1560, doi: 10.1177/0954405416673115.
[20] Gupta, V., Pandey, P.M. (2016). Experimental investigation and statistical modeling of temperature rise in rotary ultrasonic bone drilling, *Medical Engineering & Physics,* Vol. 38, No. 11, 1330-1338, doi: 10.1016/j.medengphy.2016.08.012.
[21] Alam, K., Mitrofanov, A.V., Silberschmidt, V.V. (2011). Experimental investigations of forces and torque in conventional and ultrasonically-assisted drilling of cortical bone, *Medical Engineering & Physics,* Vol. 33, No. 2, 234-239, doi: 10.1016/j.medengphy.2010.10.003.
[22] Shakouri, E., Abbasi, M. (2018). Investigation of cutting quality and surface roughness in abrasive water jet machining of bone, *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine,* Vol. 232, No. 9, 850-861, doi: 10.1177/0954411918790777.
[23] Cem Sener, B., Dergin, G., Gursoy, B., Kelesoglu, E., Slih, I. (2009). Effects of irrigation temperature on heat control in vitro at different drilling depths, *Clinical Oral Implant Research*, Vol. 20, No. 3, 294-298, doi: 10.1111/j.1600-0501.2008.01643.x.
[24] Augustin, G., Davila, S., Udilljak, T., Staroveski, T., Brezak, D., Babic, S. (2012). Temperature changes during cortical bone drilling with a newly designed step drill and an internally cooled drill, *International Orthopaedics (SICOT),* Vol. 36, No. 7, 1449-1456, doi: 10.1007/s00264-012-1491-z.
[25] Shakouri, E., Haghighi Hassanalideh, H., Gholampour, S. (2018). Experimental investigation of temperature rise in bone drilling with cooling: A comparison between modes of without cooling, internal gas cooling, and external liquid cooling, *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine,* Vol. 232, No. 1, 45-53, doi: 10.1177/0954411917742944.
[26] Staroveski, T., Brezak, D., Udiljak, T. (2015). Drill wear monitoring in cortical bone drilling, *Medical Engineering & Physics,* Vol. 37, No. 6, 560-566, doi: 10.1016/j.medengphy.2015.03.014.
[27] Augustin, G., Davila, S., Mihoci, K., Udiljak, T., Vedrina, D.S., Antabak, A. (2008). Thermal osteonecrosis and bone drilling parameters revisited, *Archives of Orthopaedic and Trauma Surgery,* Vol. 128, 71-77, doi: 10.1007/s00402-007-0427-3.
[28] Augustin, G., Davila, S., Udiljak, T., Vedrina, D.S., Bagatin, D. (2009). Determination of spatial distribution of increase in bone temperature during drilling by infrared thermography: Preliminary report, *Archives of Orthopaedic and Trauma Surgery*, Vol. 129, 703-709, doi: 10.1007/s00402-008-0630-x.

APEM journal

**Advances in Production Engineering & Management**
Letnik 16 | Številka 2 | Junij 2021 | Strani 199–211
https://doi.org/10.14743/apem2021.2.394

**ISSN 1854-6250**
Spletna stran: apem-journal.org
Izvirni znanstveni članek

# Vrtanje kosti z notranjim hlajenjem s plinom: Eksperimentalna in statistična raziskava vpliva hlajenja s $CO_2$ na zmanjšanje dviga temperature zaradi obrabe svedra

**Shakouri, E.**[a, b, *]**, Haghighi Hassanalideh, H.**[a]**, Fotuhi, S.**[b]

[a]Faculty of Engineering, Islamic Azad University-Tehran North Branch, Tehran, Iran
[b]Iranian Tajhiz Sina, its. Co., Tehran, Iran

**POVZETEK**

Vrtanje kosti je glavna faza imobilizacije mesta zloma. Med operacijami vrtanja kosti lahko temperatura preseže dovoljeno mejo 47 °C, kar povzroči nepopravljive poškodbe, kot je toplotna nekroza in resno ogrozi zdravljenje zloma. Eden od parametrov, ki vpliva na dvig temperature na mestu vrtanja, je pogostost uporabe svedra in stopnja njegove obrabe. Ta študija je poskušala ublažiti učinek obrabe svedra na dvig temperature kosti z metodo notranjega hlajenja s plinom $CO_2$ in zmanjšati tveganje pojava toplotne nekroze. Zato so bili izvedeni poskusi vrtanja pri treh vrtilnih hitrostih 1000, 2000 in 3000 rpm, v dveh stanjih brez hlajenja in z notranjim plinskim hlajenjem s $CO_2$ prek karbidnega svedra in s šestimi stanji uporabe svedra (nov, uporabljen 10-, 20-, 30-, 40- in 50-krat). Preizkusi so bili izvedeni na goveji stegnenici. Rezultati so pokazali, da se je v primeru notranjega hlajenja s plinom, ko se je uporaba svedrov povečala iz stanja nov na stanje uporabljen več kot 50-krat, temperatura na mestu izvrtine v povprečju zvišala za $\Delta T$ = 2-3 °C ($n$ = 1000 rpm), $\Delta T$ = 5-8 °C ($n$ = 2000 rpm) in $\Delta T$ = 5-7 °C ($n$ = 3000 rpm). Poleg tega je metoda notranjega hlajenja s plinom zmanjšala učinek obrabe svedra zaradi dviga temperature na mestu vrtanja in odpravila tveganje pojava toplotne nekroze ne glede na procesne parametre vrtanja.

**PODATKI O ČLANKU**

*Ključne besede:*
Kost;
Vrtanje;
Toplotna nekroza;
Obraba orodja;
Notranje hlajenje s plinom

*Kontaktna oseba:
e_shakouri@iau-tnb.ac.ir
(Shakouri, E.)

*Zgodovina članka:*
Prejet 15. marca 2021
Popravljen 18. maja 2021
Sprejet 19. maja 2021