

Oral health of the methamphetamine abuser

MARK DONALDSON AND JASON H. GOODCHILD

Methamphetamine is a highly addictive amphetamine analogue, initially synthesized in 1919.^{1,2} The pharmacologic properties of methamphetamine quickly became apparent during World War II when the drug was prescribed for many soldiers because of its stimulatory and performance-enhancing properties. Amphetamines, including methamphetamine, realized increased production and distribution in the postwar years, especially among students and athletes, until 1959, when the Food and Drug Administration (FDA) banned amphetamine-based inhalers because of their potential for abuse. However, pharmaceutical-grade methamphetamine tablets and capsules retained prescription status. Illicit methamphetamine production and use were first considered a social problem in the United States during the 1960s.³ In 1970, FDA responded to this growing problem with the passage of the U.S. Drug Abuse Regulation and Control Act.^{3,4}

Illicit methamphetamine use is a rapidly emerging topic in the lay press and medical journals and on the Internet.⁵⁻¹⁶ These articles share a common theme: methamphetamine use leads to devastating effects on health, particularly oral health.

Purpose. The pharmacology of methamphetamine is reviewed, and the effects of methamphetamine use on oral health are described.

Summary. Methamphetamine is a highly addictive amphetamine analogue, initially synthesized in 1919. Illicit methamphetamine use leads to devastating effects on health, particularly the dentition. Illegal production of methamphetamine has skyrocketed in recent years, as have the number of users. The chief complaint of methamphetamine users is xerostomia. Without the protective effects of saliva, caries development in these patients is rampant. The typical pattern of decay involves the facial and cervical areas of both the maxillary and mandibular teeth, with eventual progression to frank coronal involvement. The acidic substances used to manufacture this drug have also been implicated as a cause of tooth decay and wear in users, as has bruxism as a result of drug-induced hyperactivity. When possible, these patients should be referred to a dentist to improve

their oral health status and minimize the potential for adverse cardiovascular sequelae. Other preventive measures for methamphetamine users include stimulating saliva flow and increasing fluoride supplementation. Pharmacists should also counsel users to avoid carbohydrate-rich soft drinks in favor of water. Oral moisturizers may also be effective.

Conclusion. Methamphetamine use causes xerostomia secondary to sympathetic central nervous system activation, rampant caries caused by high-sugar intake in the absence of protective saliva, and bruxism as a result of hyperactivity. Practitioners should know how to recognize the signs of and manage the oral health of patients with a history of methamphetamine use.

Index terms: Drug abuse; Fluorides; Mechanism of action; Methamphetamine; Mouth diseases; Oral health; Patient information; Pharmacists; Toxicity

Am J Health-Syst Pharm. 2006; 63:2078-82

“Meth mouth” is commonly used to describe the numerous dental problems seen in some methamphetamine abusers, although evidence on its etiology is anecdotal. Meth mouth may be a misnomer because the presentation of decay (e.g., buccal surfaces, smooth surfaces) is indicative of generalized drug-induced

hyposalivation. What differentiates hyposalivation-related destruction from methamphetamine-related destruction are rampant decay, decreased or nonexistent oral hygiene, and bruxism.

This article reviews the pharmacology of methamphetamine and describes how to recognize and manage

MARK DONALDSON, PHARM.D., is Director of Pharmacy Services, Kalispell Regional Medical Center, Whitefish, MT, and Clinical Assistant Professor, School of Dentistry, Oregon Health and Sciences University, Portland. JASON H. GOODCHILD, D.M.D., is Assistant Professor and Director, Division of Oral Diagnosis, New Jersey Dental School, University of Medicine and Dentistry of New Jersey, Newark, and Clinical Assistant Professor, Department of Oral Medicine, School of Dental Medicine, University of Pennsylvania, Philadelphia.

Address correspondence to Dr. Donaldson at Pharmacy Services,

Kalispell Regional Medical Center, 310 Sunnyview Lane, Kalispell, MT 59901 (mdonaldson@krmc.org).

Elizabeth Prada, D.M.D., is acknowledged for her critical reading of this manuscript and management of the patient pictured in Figures 1 and 2.

Copyright © 2006, American Society of Health-System Pharmacists, Inc. All rights reserved. 1079-2082/06/1101-2078\$06.00.
DOI 10.2146/ajhp060198

patients with a history of methamphetamine use and the related oral health complications.

Pharmacologic considerations

Amphetamine analogues, including methamphetamine, are synthesized by attaching a substituent (methoxy, methyl, halogen, or sulfur) to different positions on the phenyl ring of amphetamine.¹⁷ They have been used to treat depression, attention deficit disorder, and narcolepsy and to promote weight loss.^{17,18} The federal Drug Enforcement Administration (DEA) currently classifies pharmaceutical-grade methamphetamine as a Schedule II stimulant drug. Examples of amphetamines currently approved for sale in the U.S. market include dextroamphetamine sulfate and a combination of dextroamphetamine and amphetamine salts. Methylphenidate hydrochloride, a piperidine derivative, is structurally related to amphetamine and shares the same pharmacologic properties.¹⁷ The most widely used illicit amphetamine analogues include methylenedioxyamphetamine (MDMA, ecstasy), methylenedioxyamphetamine (MDA, the love pill), methylenedioxyethamphetamine (MDEA, Eve), and nonpharmaceutical-grade methamphetamine (ice, crystal meth).

The amphetamine analogues cause hyperalertness, hyperactivity, euphoria, talkativeness, decreased appetite, and increased physical and sexual endurance.^{17,18} Mild intoxication with methamphetamine is marked by dizziness, headache, irritability, hypertension, tachycardia, mydriasis, tremor, hyperpyrexia, and hyperreflexia. Toxic doses of methamphetamine are extensions of the effects of mild intoxication and may cause confusion, diaphoresis, palpitations, nausea, vomiting, hallucinations, convulsions, and coma.^{10,17,19,20}

Methamphetamine can be snorted, smoked, swallowed, and injected. After oral administration, the time to maximum plasma concentration

(t_{\max}) is two to three hours, although the drug's effects can be felt in as little as 20 minutes.^{21,22} Methamphetamine users typically progress to snorting, smoking, or injecting the drug to decrease the onset time; the t_{\max} for injected, snorted, and smoked methamphetamine is 2–4 minutes (described as the "rush").²¹⁻²³

Methamphetamine is metabolized primarily by the liver.²¹ The drug undergoes oxidation and glucuronidation into an active metabolite (amphetamine) and two inactive metabolites (norephedrine and *p*-hydroxynorephedrine). The elimination half-life ($t_{1/2}$) of methamphetamine varies widely, depending on urine pH. At pH 6–8, the $t_{1/2}$ is approximately 12 hours and is relatively constant, regardless of the route of administration.^{11,19,21} One potential strategy for the treatment of acute overdose is acidification of the urine to increase elimination.^{17,21} Although this is theoretically true, that a weak base such as methamphetamine will be ionized in an acidic environment, this practice is not currently recommended because of the risk of rhabdomyolysis and renal failure.²⁴ The cytochrome P-450 (CYP) isoenzyme 2D6 is involved in the oxidation of methamphetamine to amphetamine. Drugs that inhibit or induce CYP 2D6 (e.g., cimetidine, paroxetine, citalopram, sertraline, dexamethasone, tramadol) may alter methamphetamine metabolism, although no changes in clinical effect may be noted.^{25,26}

Methamphetamine is extremely addictive and a potent stimulant of the central nervous system, causing a release of norepinephrine and dopamine at the synaptic cleft while blocking their reuptake.²⁷ This results in depletion of available neurotransmitters and possibly contributes to rapid tolerance and eventual withdrawal symptoms. Methamphetamine, structurally similar to epinephrine, increases both systolic and diastolic blood pressures, which is usually accompanied by reflex bradycardia. The respiratory center is also

stimulated, causing an increase in both the rate and depth of respiration.¹⁷

Recent statistics

Illegal production of methamphetamine has skyrocketed in recent years and is widespread throughout the Pacific, Southwest, and West Central United States, as well as prison populations.^{5-8,20,28,29} In 2001, police raided illegal methamphetamine laboratories in 46 states, with Missouri having the highest number of incidents at 2207.⁷ From 2002 to 2004, Missouri law enforcement seized more than 8000 methamphetamine laboratories.⁷ According to the 2002 Arrestee Drug Abuse Monitoring Program, Honolulu, Hawaii, had the highest percentage of male and female arrestees testing positive for methamphetamine use, followed by Sacramento and San Jose, California, respectively.²⁹

Most alarming is the number of young people who are abusing methamphetamine. The 2003 National Survey on Drug Use and Health reported that 12.3 million Americans age 12 years or older have used methamphetamine at least once.²⁹ A survey conducted by the Centers for Disease Control and Prevention found that 9.8% of high-school students had used methamphetamine.³⁰

Methamphetamine is known by many names: ice, speed, fire, crank, chalk, crystal meth, and poor man's cocaine. Illegal methamphetamine can be produced by several methods, using ingredients such as ephedrine or pseudoephedrine, hydrochloric acid, iodine, ether, lye, chloroform, freon, Drano, lighter fluid, lantern fuel, rock salt, dry ice, battery acid, red phosphorus, and propane.^{12,14}

Because the manufacturing of methamphetamine requires highly toxic and volatile chemicals, production is extremely hazardous. For every pound of methamphetamine manufactured, 6 pounds of toxic waste are produced.^{12,23} In many cases the remnants, waste products, and facilities involved in the production

of methamphetamine are abandoned after use, or the waste produced is flushed down the drain. Dwellings where methamphetamine laboratories have been discovered are often condemned and eventually destroyed because methamphetamine production renders the home uninhabitable and a health risk for any occupant. In 2001, 10 pounds of methamphetamine could be produced in a 24-hour period, with each pound selling for \$3,500–\$25,000 (\$20–\$350 per gram). A chronic methamphetamine user on a “binge” can consume 8–12 g in one day.²⁰

Oral health considerations

The chief complaint of methamphetamine abusers is xerostomia, or dry mouth.^{31–34} Several factors contribute to this condition. Methamphetamine users are hyperactive and rarely stop to eat or drink anything during times of acute drug use, leading to generalized dehydration. Rather than drink water, methamphetamine users report craving sugar and typically drink large quantities of nondiet, caffeine-rich soft drinks; Mountain-Dew is commonly mentioned as a beverage of choice.^{6,14} Methamphetamine also increases sympathetic activity in the central nervous system, reducing saliva secretion by stimulation of inhibitory α_2 receptors and resulting in reductions in unstimulated salivary flow.³⁵ What little saliva is produced is high in protein, thereby increasing the patient’s sensation of oral dryness.³⁴

Without the protective effects of saliva, caries development in these patients is rampant. The typical pattern of decay involves the facial and cervical areas of both the maxillary and mandibular teeth, with eventual progression to frank coronal involvement. Unlike other forms of caries caused by drug- or postradiation-induced xerostomia, the caries of a patient who uses methamphetamine progress more slowly.¹⁰ Although users will binge for days or weeks, during which time they practice no

oral hygiene, there may be times of methamphetamine abstinence when decay progression is slowed by some oral hygiene measures. Interestingly, despite generalized severe caries with obvious pulpal involvement, patients often report no pain but may seek the advice of a pharmacist for cosmetic or supportive assistance.

The acidic substances used to manufacture this drug have also been implicated as a cause of tooth decay and wear in methamphetamine users.^{9,14} When methamphetamine containing phosphoric, sulfuric, or muriatic acid is smoked, the teeth are bathed in acid, contributing to enamel erosion and breakdown. In a study by Navarro et al.,²⁸ high levels of MDMA detected in the saliva accounted for a small decrease in salivary pH, from 7.4 to 6.9. Since the critical pH at which enamel demineralizes is 5.5, the pH change after ingestion of MDMA does not significantly contribute to caries formation.

Another contributing factor to tooth wear in these patients is bruxism. Methamphetamine users are extremely active and “wired” during times of intense drug use. As the drug effects wane, users begin “tweaking,” characterized by restlessness, anxiety, irritability, fatigue, and dysphoria.²³ During times of acute use, users tend to grind and clench their jaws, further contributing to tooth wear.³⁵

Figures 1 and 2 show retracted and maxillary occlusal views of a 32-year-old methamphetamine user who was recently seen at an oral medicine clinic at the University of Pennsylvania. The patient attributed the destruction of his teeth to a 4-year history of methamphetamine use (smoking only), although he professed abstinence for the 18 months leading up to this appointment. While numerous dental problems were evident upon examination, he reported no pain and wished to have his teeth restored.

The patient was asked about his history of methamphetamine use, with particular emphasis on his den-

tal history. While using the drug, his primary complaints were extreme dry mouth and a constant craving for sugar, particularly soda. He reported consuming approximately 12 16-ounce nondiet cola drinks per day. He reported brushing his teeth during active methamphetamine use, but he would go days or weeks without brushing or practicing any oral hygiene during times of heavy drug use. He stopped using methamphetamine 18 months ago and claimed to routinely brush his teeth twice daily.

After a comprehensive examination, proper oral hygiene was reviewed, emphasizing fluoride supplementation. A neutral fluoride product was prescribed (PreviDent 5000, Colgate-Palmolive), and dietary modification, such as the elimination of nondiet carbonated beverages, was discussed. Because of the extensive decay, the initial treatment plan included prophylaxis and caries control to determine tooth restorability. Nonrestorable teeth were extracted and edentulous areas were restored with either implant-supported fixed partial dentures or conventional removable partial dentures.

Oral health treatment of methamphetamine users

When speaking with patients who report xerostomia, unexplained rampant caries, and accelerated tooth wear from bruxism, pharmacists should consider methamphetamine abuse as a possible cause. In addition, because of the anorexiant properties of methamphetamine, patients may appear malnourished or frail (appendix). Pharmacists should complete a thorough medical history of these patients, including questions about illicit drug use. Although patients may be hesitant to disclose a history of drug use to their physicians and dentists for fear of being refused treatment, pharmacists are encouraged to show concern for patients’ dental complaints and express positive regard.³⁶ If confirmation of drug use is received, the pharmacist

Figure 1. Retracted intraoral photograph of a 32-year-old methamphetamine user at initial presentation.



Figure 2. Occlusal view of a 32-year-old methamphetamine user at initial presentation.



should refer the patient to his or her physician, dentist, and substance abuse rehabilitation facility.

When possible, these patients should be referred to a dentist to improve their oral health status and minimize the potential for adverse cardiovascular sequelae. If dental treatment must be rendered to a patient who has recently used methamphetamine, the dentist must be careful when administering local anesthesia containing a vasoconstrictor. The duration of action for methamphetamine can be 8–12 hours and up to 24 hours in cases of intoxication.^{17,18,20,23,37} If local anesthesia must be administered during

this time, a plain solution (i.e., sterile water for injection or saline) without a vasoconstrictor should be used. In addition, the use of local anesthetic containing a vasoconstrictor should be further avoided for 24 hours after methamphetamine use. This is to allow all clinical effects to cease and to allow the drug to be eliminated from the patient's body. Although only 75% of methamphetamine may be eliminated after 24 hours, evidence suggests that the cardiovascular and clinical effects cease before the drug has been significantly eliminated.³⁸ Postoperatively, opioid analgesics should be avoided in patients at risk for drug abuse and increased ventila-

tory depression.^{13,19,39} Dental pain, principally mediated by inflammation, should be controlled with non-steroidal antiinflammatory drugs. Fluoride should be administered via trays, gels, rinses, or varnishes, and basic oral hygiene skills should be reviewed. A neutral fluoride versus acidulated product is recommended for patients reporting xerostomia to buffer the oral pH and help remineralize tooth structure. Sodium fluoride 1.1% is recommended, such as Karigel (Young Dental Manufacturing, Earth City, MO) and PreviDent 5000.

Other preventive measures for methamphetamine users include stimulating saliva flow and increasing fluoride supplementation. Saliva substitutes have been reported to be ineffective, while pharmacologic agents to improve saliva flow appear helpful.⁴⁰ The two most common systemic agents available by prescription are the secretagogues pilocarpine hydrochloride (Salagen, MGI Pharma Inc.) and cevimeline hydrochloride (Evovac, Daiichi Pharmaceutical Co.), both of which are believed to act on the muscarinic receptors in the salivary glands.⁴¹ These medications can improve salivary flow, but the chewing of sugarless gum can also be beneficial.^{10,34}

Pharmacists should counsel methamphetamine users to avoid carbohydrate-rich soft drinks in favor of water. Although the effectiveness of commercially available oral moisturizers, such as Optimoist (Colgate-Palmolive), has not been shown in this patient population, these agents have increased salivary flow rates in other xerostomic populations and may be worth consideration for methamphetamine users.⁴² The same is true for the Biotene product lines (e.g., Dry Mouth Toothpaste, Gentle Mouthwash, Dry Mouth Gum, and Oral Balance Gel; Laclede Co.), whose use has caused marked subjective improvements in patients with similar clinical xerostomic presentations due to different pathogenesis.⁴³

Conclusion

Methamphetamine use causes xerostomia secondary to sympathetic central nervous system activation, rampant caries caused by high-sugar intake in the absence of protective saliva, and bruxism as a result of hyperactivity. Practitioners should know how to recognize the signs of and manage the oral health of patients with a history of methamphetamine use.

References

1. Logan BK. Amphetamines: an update on forensic issues. *J Anal Toxicol.* 2001; 25:400-4.
2. Greater Dallas Council on Alcohol and Drug Abuse. Methamphetamine. www.gdcada.org/statistics/meth/meth2.htm (accessed 2005 Feb 17).
3. The Vaults of Erowid. Methamphetamine timeline. www.erowid.org/chemicals/meth/meth_timeline.php (accessed 2006 Apr 10).
4. Drug Enforcement Administration. Comprehensive Drug Abuse Prevention and Control Act of 1970. www.dea.gov/pubs/csa.html (accessed 2006 Jun 8).
5. Davey M. Grisly effect of one drug: 'meth mouth.' <http://vadental.org/docs/timesarticlemeth.pdf> (accessed 2005 Dec 12).
6. Brunswick M. Meth users can look forward to gumming their food. <http://dpna.org/resources/druginfo/methgums.htm> (accessed 2005 Dec 6).
7. Jefferson DJ. America's most dangerous drug. www.msnbc.msn.com/id/8770112 (accessed 2005 Dec 6).
8. Kinkead LD, Romboy D. Meth mouth: ugly legacy of drug is taxing Utah jail, prison medical budgets. <http://deseretnews.com/dn/view/0,1249,600140819,00.html> (accessed 2006 Feb 13).
9. American Dental Association. Methamphetamine use and oral health. *J Am Dent Assoc.* 2005; 136:1491.
10. Rhodus NL, Little JW. Methamphetamine abuse and "meth mouth." *Northwest Dent.* 2005; 84:29,31,33-7.
11. Venker D. Crystal methamphetamine and the dental patient. *Iowa Dent J.* 1999; 85:34.
12. Shaner JW. Caries associated with methamphetamine abuse. *J Mich Dent Assoc.* 2002; 84:42-7.
13. American Dental Association. Methamphetamine use (meth mouth). www.ada.org/prof/resources/topics/methmouth.asp (accessed 2006 Feb 13).
14. Jones KD. Viewpoint: spotting meth mouth. www.ada.org/prof/resources/pubs/adanews/adanewsarticle.asp?articleid=1517 (accessed 2006 Feb 13).

15. Palmer C. Special report: "meth mouth" tells devastating story. www.ada.org/prof/resources/pubs/adanews/adanewsarticle.asp?articleid=1523 (accessed 2005 Dec 6).
16. Palmer C. Dr. Brandjord briefs senators on dental impact of meth abuse. www.ada.org/prof/resources/pubs/adanews/adanewsarticle.asp?articleid=1764 (accessed 2006 Feb 13).
17. Hoffman BB. Catecholamines, sympathomimetic drugs, and adrenergic receptor antagonists. In: Hardman JG, Limbird LE, eds. Goodman and Gilman's the pharmacological basis of therapeutics. 10th ed. New York: McGraw-Hill; 2001:215-60.
18. Lacey CF, Goldman MP, Lanci LL et al. Drug information handbook. 13th ed. Hudson, OH: Lexi-Comp; 2005:971-2.
19. Lee CYS, Heffez LB, Mohammadi H. Crystal methamphetamine abuse: a concern to oral and maxillofacial surgeons. *J Oral Maxillofac Surg.* 1992; 50:1052-4.
20. Office of National Drug Control Policy. Methamphetamine. <http://whitehousedrugpolicy.org/publications/pdf/ncj197534.pdf> (accessed 2006 Jul 31).
21. Schepers RJ, Oyler JM, Joseph RE Jr et al. Methamphetamine and amphetamine pharmacokinetics in oral fluid and plasma after controlled oral methamphetamine administration to human volunteers. *Clin Chem.* 2003; 49:121-32.
22. Alberta Alcohol and Drug Abuse Commission. Amphetamines. http://corp.aadac.com/content/corporate/other_drugs/amphetamines_beyond_abcs.pdf (accessed 2006 Jul 31).
23. Lineberry TW, Bostwick JM. Methamphetamine abuse: a perfect storm of complications. *Mayo Clin Proc.* 2006; 81:77-84.
24. Scandling J, Spital A. Amphetamine-associated myoglobinuric renal failure. *South Med J.* 1982; 75:237-40.
25. Olkkola KT, Ahonen J. Drug interactions. *Curr Opin Anaesthesiol.* 2001; 14:411-6.
26. Sweeney BP, Bromilow J. Liver enzyme induction and inhibition: implications for anaesthesia. *Anaesthesia.* 2006; 61:159-77.
27. Williams F, Turner T. Adrenergic pharmacology. In: Golan DE, Taschjian AH, Armstrong EJ et al., eds. Principles of pharmacology. The pathophysiologic basis of drug therapy. Baltimore: Lippincott Williams and Wilkins; 2005:107-17.
28. Navarro M, Pichini S, Farre M et al. Usefulness of saliva for measurement of 3,4-methylenedioxyamphetamine and its metabolites: correlation with plasma drug concentrations and effect of salivary pH. *Clin Chem.* 2001; 47:1788-95.
29. Substance Abuse and Mental Health Services Administration. National Survey on Drug Use and Health. <http://oas.samhsa.gov/nsduh.htm> (accessed 2006 Feb 14).
30. Centers for Disease Control and Prevention. Youth risk behavior surveillance—United States, 2001. www.cdc.gov/mmwr/preview/mmwrhtml/ss5104a1.htm (accessed 2006 Feb 14).

31. Forest D. Methamphetamine and oral health: reality or myth. *J Dent Que.* 2005; 42:445.
32. Shafer J. The meth-mouth myth. www.slate.com/id/2124160/ (accessed 2005 Dec 6).
33. Lewis DM. Xerostomia: a clinical approach. *J Okla Dent Assoc.* 2005; 97:22-5.
34. Saini TS, Edwards PC, Kimmes NS et al. Etiology of xerostomia and dental caries among methamphetamine abusers. *Oral Health Prev Dent.* 2005; 3:189-95.
35. Curtis EK. Meth mouth: a review of methamphetamine abuse and its oral manifestations. *Gen Dent.* 2006; 54:125-9.
36. McDaniel TF, Miller D, Jones R et al. Assessing patient willingness to reveal medical history information. *J Am Dent Assoc.* 1995; 126:375-9. [Erratum, *J Am Dent Assoc.* 1995; 126:560.]
37. BC Partners for Mental Health and Addictions Information. Methamphetamine. www.heretohelp.bc.ca (accessed 2006 Feb 14).
38. Newton TF, De La Garza R II, Kalechstein AD et al. Cocaine and methamphetamine produce different patterns of subjective and cardiovascular effects. *Pharmacol Biochem Behav.* 2005; 82:90-7.
39. American Dental Association. ADA warns of methamphetamine's effect on oral health. www.ada.org/public/media/releases/0508_release01.asp (accessed 2006 Jul 27).
40. Givens E. Update on xerostomia: current treatment modalities and future trends. *Gen Dent.* 2006; 54:99-101.
41. Grisius MM. Salivary gland dysfunction: a review of systemic therapies. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 2001; 92:156-62.
42. Rhodus NL, Bereuter J. Clinical evaluation of a commercially available oral moisturizer in relieving signs and symptoms of xerostomia in postirradiation head and neck cancer patients and patients with Sjogren's syndrome. *J Otolaryngol.* 2000; 29:28-34.
43. Warde P, Kroll B, O'Sullivan B et al. A Phase II study of Biotene in the treatment of postradiation xerostomia in patients with head and neck cancer. *Support Care Cancer.* 2000; 8:203-8.

Appendix—Signs of methamphetamine use

- Malnourishment
- Disregard of personal hygiene
- Frail appearance, history of losing weight
- Sores on the body and face ("crank bugs")
- Personality changes (e.g., hyperactivity, irritability)
- Unexplained rapid development of buccal or cervical decay
- Extreme evidence of bruxism, including wear spots and fractures