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Original Articles

HOLMIUM:YAG LITHOTRIPSY YIELDS SMALLER FRAGMENTS THAN LITHOCLAST, PULSED DYE LASER OR ELECTROHYDRAULIC LITHOTRIPSY

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ABSTRACT

Purpose: The mechanism of lithotripsy differs among electrohydraulic lithotripsy, mechanical lithotripsy, pulsed dye lasers and holmium:YAG lithotripsy. It is postulated that fragment size from each of these lithotrites might also differ. This study tests the hypothesis that holmium:YAG lithotripsy yields the smallest fragments among these lithotrites.

Materials and Methods: We tested 3F electrohydraulic lithotripsy, 2 mm. mechanical lithotripsy, 320 μm. pulsed dye lasers and 365 μm. holmium:YAG fiber on stones composed of calcium hydrogen phosphate dihydrate, calcium oxalate monohydrate, cystine, magnesium ammonium phosphate and uric acid. Fragments were dessicated and sorted by size. Fragment size distribution was compared among lithotrites for each composition.

Results: Holmium:YAG fragments were significantly smaller on average than fragments from the other lithotrites for all compositions. There were no holmium:YAG fragments greater than 4 mm., whereas there were for the other lithotrites. Holmium:YAG had significantly greater weight of fragments less than 1 mm. compared to the other lithotrites.

Conclusions: Holmium:YAG yields smaller fragments compared to electrohydraulic lithotripsy, mechanical lithotripsy or pulsed dye lasers. These findings imply that fragments from holmium:YAG lithotripsy are more likely to pass without problem compared to the other lithotrites. Furthermore, the significant difference in fragment size adds evidence that holmium:YAG lithotripsy involves vaporization.

KEY WORDS: urinary calculi; lithotripsy; lithotripsy, laser; holmium

The mechanisms of electrohydraulic lithotripsy, mechanical lithotripsy (lithoclast) and pulsed dye laser lithotripsy are well understood.[1-4] Electrohydraulic lithotripsy creates an expanding cavitation bubble that collapses on itself, releasing an acoustic pressure wave or shock wave. Mechanical lithotripsy (Lithoclast) fragments calculi by a mechanism akin to a pneumatic jackhammer. Pulsed dye lasers energy vaporizes the medium creating an expanding cavitation bubble that leads to an acoustic pressure wave. The process of creating a vapor plasma requires specific conditions necessary to achieve laser induced shock wave lithotripsy. In contast, the mechanism of holmium:YAG lithotripsy is not well understood but it is believed to involve direct stone absorption of laser energy and not to involve laser induced shock wave lithotripsy.[4]

Because the lithotripsy mechanisms of electrohydraulic lithotripsy, mechanical lithotripsy, pulsed dye lasers, and holmium:YAG lithotripsy differ, we postulated that the fragment size might also differ. Clinically, holmium:YAG lithotripsy seems to create minute fragments, a result that appears different endoscopically compared to the other lithotrites.[5] The purpose of this study was to characterize the fragment size from electrohydraulic lithotripsy, mechanical lithotripsy, pulsed dye lasers and holmium:YAG lithotripsy. It was our hypothesis that holmium:YAG lithotripsy yields the smallest fragments.

MATERIALS AND METHODS

Urinary calculi were obtained from a stone composition laboratory (Louis C. Herring Co., Orlando, Florida). Calculi were included from calcium oxalate monohydrate, calcium hydrogen phosphate dihydrate (or calcium phosphate), cystine, magnesium ammonium phosphate hexohydrate, and uric acid. Calculi were included only if compositions were 95% pure or greater. These compositions were chosen since they are considered resistant to lithotripsy (except magnesium ammonium phosphate hexohydrate). Magnesium ammonium phosphate hexohydrate was included due to its propensity to form staghorn calculi. Each calculus was weighed (dry weight). Calculi were divided among different lithotrites. The weight distribution for each group and composition were compared with analysis of variance to ensure that no size discrepancy existed.

Lithotripsy was done using electrohydraulic lithotripsy, mechanical lithotripsy, pulsed dye laser lithotripsy, or holmium:YAG lithotripsy. Electrohydraulic lithotripsy was done with the ACMI 3.0F fiber and powered with the ACMI AEH-2

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unit.* Energy was started at 50 v. using short intermittent pulses. The fiber tip was kept 1 to 2 mm. off of the stone surface. A new fiber was used for each stone. When fibers appeared to lose efficacy, they were replaced with new fibers. When no apparent fragmentation was achieved, the energy levels were sequentially increased by 5 v. increments until fragmentation proceeded. A maximum energy setting of 100 v. was used. The 2 mm. Swiss Lithoclast† probe was used for mechanical lithotripsy. The probe was placed in contact with the calculus. Pressure settings were set at 3 bars, using continuous mode. The 320 μm. fiber powered by the MDL-3000 Laser Tripter‡ was used for pulsed dye lasers. The fiber tip contacted the calculus. Energy settings commenced at 30 mJ. and were raised in 10 mJ. increments until fragmentation was seen, up to a maximum energy of 100 mJ. The 365 μm. fiber powered by VersaPulse Select§ unit was used for holmium:YAG lithotripsy. The fiber tip was placed in contact mode. Energy was started at 0.5 J. at 6 Hz. If fragmentation was not efficient, the energy or frequency was increased incrementally until a desired effect, not exceeding a maximum of 1.0 J. at 15 Hz.

For all lithotripsy modalities each calculus was placed in 60 cc specimen containers filled with normal saline just before lithotripsy. The calculus was placed in a stone basket for stabilization. If the calculus fell out of the basket, it was left to the discretion of the surgeon to reposition the calculus in the basket or to continue lithotripsy without the basket. Lithotripsy continued until no further fragmentation could be achieved at the maximal power settings for the lithotrite.

Each container (containing calculus fragments and saline) was emptied into a test tube. Test tubes were centrifuged at 6,000 rpm for 60 minutes. The supernatant was discarded. Fragments were resuspended in 10 cc deionized water and re-centrifuged at 6,000 rpm for 60 minutes. The supernatant was discarded. Fragments were placed in a −80C freezer for 2 hours. Specimens were removed from the freezer and dessicated using a vacuum lyophilizer to sublimate water off the calculi. Lyophilization lasted 24 hours or greater until test tubes were at room temperature, indicating complete sublimation of ice from the specimen.

Fragments were passed through sequential geological brass sieves. The sieve openings were 4, 2, 1.4 and 1 mm. Fragments for each size were weighed. The weight of stone fragments recovered was divided by the original stone weight to determine recovery rates. Values were compared for each lithotrite and composition. Analysis of variance and Tukey's Student's range test were used for statistics. The weights of fragments in each size range were converted to a percent weight of the total recovered weight. All stone percentages for a given lithotrite and composition were averaged and compared. Chi-square analysis was used for statistics.

Another analysis was computed to estimate the size distribution. The computation started with the mean percent weight of stone in each category (greater than 4, 2 to 4, 1.4 to 2 mm., 1 to 1.4, and less than 1 mm.). Each group was assigned the values of 4, 3, 1.7, 1.2 and 1 mm., respectively. A worksheet was made assuming 100 fragments per stone in proportion to the percent weight of stones per group, assigning the values above for each stone. For example, if a stone had 37% of the weight of its fragments falling between 2 and 4 mm. then 37 of 100 fragments were considered to measure 3 mm. Analysis of variance and Tukey's Student's range test were used for statistics. For all analyses, statistics were computed on a computer software program. Statistical significance was defined at a $p < 0.05$.

RESULTS

For each stone composition and lithotrite 3 separate calculi were used. Table 1 shows the original dry weight of calculi used and that the calculi were well matched by weight. Table 2 lists the recovery rate of calculi by composition and lithotrite. Fragment distribution among each size group is shown in figures 1 to 5. For each composition $p < 0.001$ was noted when mean percent calculus weight distribution among groups was compared among lithotrites. The computed size distribution is shown in table 3. Pairwise comparisons showed that mean holmium:YAG lithotripsy stone size was significantly smaller than the other lithotrites for all compositions. There was no significant fragment size difference among electrohydraulic lithotripsy, mechanical lithotripsy and pulsed dye lasers for cystine, magnesium ammonium phosphate hexohydrate and uric acid. For calcium oxalate monohydrate, pulsed dye lasers fragment size was intermediate between holmium:YAG lithotripsy and mechanical lithotripsy and electrohydraulic lithotripsy. For calcium phosphate, mechanical lithotripsy and pulsed dye lasers fragment sizes were intermediate between holmium:YAG lithotripsy and electrohydraulic lithotripsy.

An observation noted for 2 pulsed dye laser stones (1 of 3 calcium phosphate and 1 of 3 calcium oxalate monohydrate), 6 mechanical lithotripsy stones (2 of 3 calcium phosphate, 2 of 3 calcium oxalate monohydrate, 1 of 3 magnesium ammonium phosphate hexohydrate, and 1 of 3 uric acid), all holmium:YAG lithotripsy stones (3 of 3 for each of calcium phosphate, calcium oxalate monohydrate, cystine, magnesium ammonium phosphate hexohydrate and uric acid) was that tiny stone debris gradually filled the specimen container as lithotripsy progressed, obscuring visualization. Among some holmium:YAG lithotripsy calculi vapor was seen arising from the container. Among all of the holmium:YAG lithotripsy cystine calculi a sulfuric odor was appreciated as vapor arose from the container.

DISCUSSION

This study revealed that holmium:YAG lithotripsy overall yielded smaller fragments than pulsed dye lasers, mechanical lithotripsy or electrohydraulic lithotripsy. Holmium:YAG lithotripsy was the only lithotrite not to yield fragments greater than 4 mm. It had a significantly greater weight of fragments less than 1 mm. compared to pulsed dye, mechanical or electrohydraulic lithotripsy. These results are particularly compelling since these findings occurred consistently among all compositions tested. Furthermore,

TABLE 1. *Calculus dry weight before lithotripsy*

	Mean ± SD (gm.)				
	Electrohydraulic Lithotripsy	Mechanical Lithotripsy	Pulsed Dye Lasers	Holmium:YAG Lithotripsy	p Value
Calcium phosphate	1.07 ± 0.41	1.20 ± 0.62	0.97 ± 0.32	1.08 ± 0.49	0.95
Calcium oxalate monohydrate	0.19 ± 0.19	0.16 ± 0.13	0.17 ± 0.13	0.18 ± 0.16	>0.99
Cystine	0.69 ± 0.69	0.76 ± 0.61	0.76 ± 0.60	0.67 ± 0.68	>0.99
Magnesium ammonium phosphate hexohydrate	2.73 ± 1.44	2.04 ± 1.12	1.91 ± 0.47	2.33 ± 0.13	0.74
Uric acid	1.47 ± 1.44	1.29 ± 1.18	1.34 ± 1.44	1.45 ± 1.27	>0.99

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* Circon-ACMI, Stamford, Connecticut.
† Microvasive, Watertown, Massachusetts.
‡ Candela, Wayland, Massachusetts.
§ Coherent Medical Group, Palo Alto, California.

TABLE 2. *Calculus mass recovery rate*

	% Mean ± SD				p Value
	Electrohydraulic Lithotripsy	Mechanical Lithotripsy	Pulsed Dye Lasers	Holmium:YAG Lithotripsy	
Calcium phosphate	97 ± 1	92 ± 6	90 ± 5	85 ± 5	0.08
Calcium oxalate monohydrate	98 ± 1	94 ± 5	95 ± 2	89 ± 8	0.27
Cystine	98 ± 2	93 ± 6	97 ± 2	83 ± 8	0.02*
Magnesium ammonium phosphate hexohydrate	97 ± 1	94 ± 5	95 ± 3	83 ± 3	0.004†
Uric acid	96 ± 2	92 ± 6	98 ± 1	88 ± 7	0.13

* Pairwise differences at α <0.05 for electrohydraulic lithotripsy, mechanical lithotripsy, pulsed dye lasers, versus mechanical lithotripsy, holmium:YAG lithotripsy were statistically different.

† Pairwise differences for magnesium ammonium phosphate hexohydrate at α <0.05 for holmium:YAG lithotripsy was different than electrohydraulic lithotripsy, mechanical lithotripsy and pulsed dye lasers.

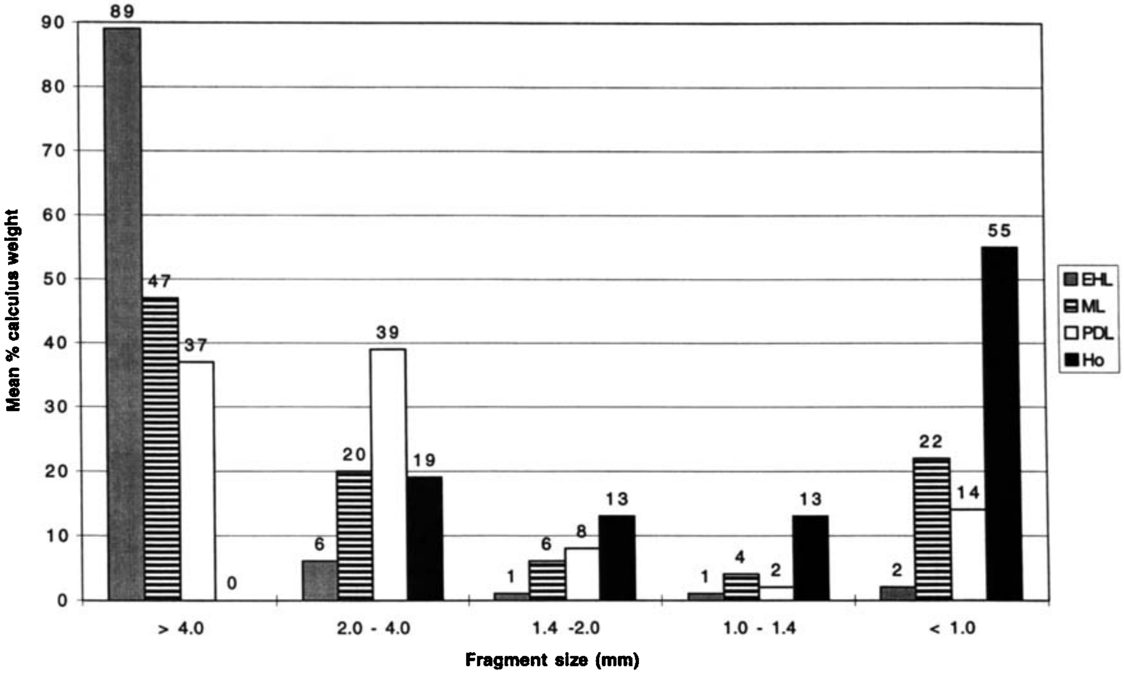

FIG. 1. Mean percent weight of fragments by lithotrite of stones greater than 4, 2.0 to 4.0, 1.4 to 2.0, 1.0 to 1.4, and less than 1 mm. for calcium hydrogen phosphate dihydrate (or calcium phosphate). Percent values are shown for each bar. Electrohydraulic lithotripsy, (*EHL*), mechanical lithotripsy (*ML*) and pulsed dye lasers (*PDL*) fragments predominate for groups 2.0 to 4.0 and greater than 4 mm., whereas holmium:YAG lithotripsy (*Ho*) fragments predominate for groups less than 1.0 and 1.0 to 1.4 mm. (p <0.001).

when holmium:YAG lithotripsy was excluded from analysis, there was no consistent trend favoring pulsed dye lasers, mechanical lithotripsy or electrohydraulic lithotripsy (fig. 1 to 5 and table 3). The corollary is that compared to electrohydraulic lithotripsy, mechanical lithotripsy and pulsed dye lasers, holmium:YAG lithotripsy may need less basketing and poses less risk of leaving behind sizable residual fragments that may be problematic. The differences provide further evidence that the mechanism of lithotripsy for holmium is unique. The proposal that holmium:YAG lithotripsy involves vaporization is supported by these results.[6]

The mechanisms of electrohydraulic lithotripsy, mechanical lithotripsy and pulsed dye lasers have been elucidated.[1–4] In contrast, the mechanism of holmium:YAG lithotripsy is poorly defined but is thought to require the absorption of laser energy by the calculus. This mechanism is presumed from several studies. In 1 study, when holmium:YAG pulsed duration was Q-switched and shortened to 500 nanoseconds, bubble expansion increased and was associated with spherical expansion, a thermoelastic expansion wave and a high amplitude acoustic pressure wave.[7] However, as nonQ-switched holmium:YAG pulsed duration was increased, the bubble expansion lasted longer, assumed erratic shapes, had no measurable thermoelastic expansion wave and collapsed on itself asymmetrically with small amplitude collapse waves. The implication is that (nonQ-switched) holmium:YAG at a 250 μs. pulsed duration most likely does not create the conditions necessary for laser induced shock wave lithotripsy. In a study of various lasers used on bovine shank bone ablation of calcium and phosphorous occurred at lasers of wavelengths of 308 to 2,800 nm. in the absence of plasma generation.[6] Furthermore, the ablation debris measured 10 μm., was composed of calcium hydroxyapatite and appeared relatively undisturbed. The authors proposed a 2-component concept of ablation where superheated soft tissue is vaporized so rapidly that fast vapor flow velocities of ablated soft tissue accelerate calcium granules off of the bone. In an experimental study of holmium:YAG the pulsed energy required to damage guide wires varied directly with the cosine of angle of laser incidence and inversely with the square of the distance.[8] These relationships validate the concept that holmium:YAG effect requires target absorption of laser energy, as opposed to laser induced shock wave lithotripsy.

These experimental findings also concur with clinical observations. Previously, we reported that holmium:YAG cystolithotripsy appears to debulk the calculus without obvious fragmentation, while producing an endoscopic appearance akin to a "snowstorm" of tiny stone particles.[5] In another

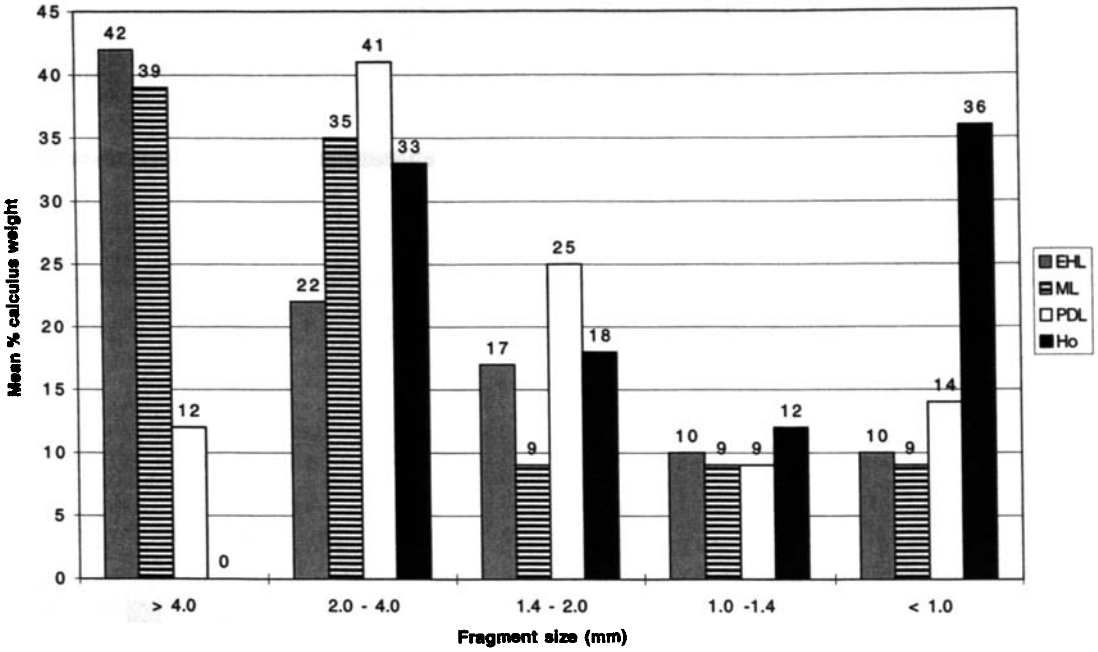

FIG. 2. Mean percent weight of fragments by lithotrite of stones greater than 4, 2.0 to 4.0, 1.4 to 2.0, 1.0 to 1.4 and less than 1 mm. for calcium oxalate monohydrate. Percent values are shown for each bar. Electrohydraulic lithotripsy, (*EHL*), mechanical lithotripsy (*ML*) and pulsed dye lasers (*PDL*) fragments predominate for group greater than 4 mm., whereas holmium:YAG lithotripsy (*Ho*) fragments predominate for group less than 1.0 mm. ($p < 0.001$).

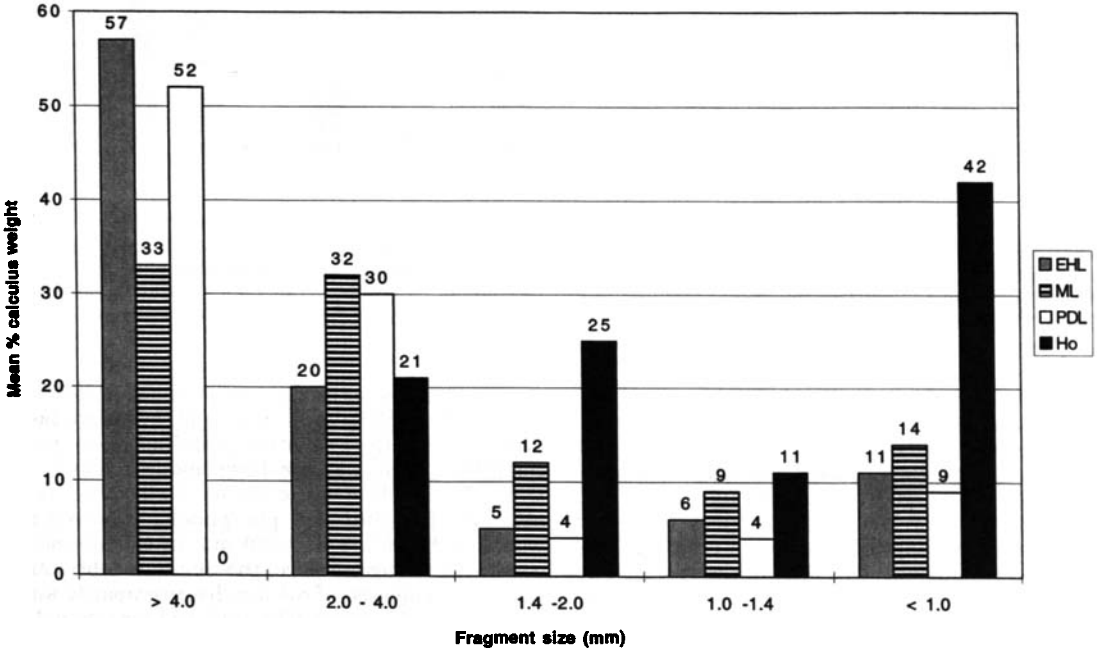

FIG. 3. Mean percent weight of fragments by lithotrite of stones greater than 4, 2.0 to 4.0, 1.4 to 2.0, 1.0 to 1.4 and less than 1 mm. for cystine. Percent values are shown for each bar. Electrohydraulic lithotripsy (*EHL*), mechanical lithotripsy (*ML*) and pulsed dye lasers (*PDL*) fragments predominate for group greater than 4 mm., and mechanical lithotripsy and pulsed dye lasers fragments for group 2.0 to 4.0 mm. whereas holmium:YAG lithotripsy (*Ho*) fragments predominate for groups less than 1.0 and 1.4 to 2.0 mm. ($p < 0.001$).

report we compared electrohydraulic lithotripsy and holmium:YAG for ureteroscopic lithotripsy.[9] For ureteral calculi less than 15 mm. electrohydraulic lithotripsy was faster than holmium:YAG but had a lower stone-free outcome at the end of ureteroscopy. For ureteral calculi 15 mm. or greater holmium:YAG was faster and more successful than electrohydraulic lithotripsy. We proposed that these findings occurred for small calculi because little electrohydraulic lithotripsy power is required to effect fragmentation. The resulting fragments are few and easy to basket. In contrast, for large calculi more electrohydraulic lithotripsy power is needed to achieve sufficient fragmentation with increased risk of mucosal injury, bleeding and impaired endoscopic vision. More basketing and irrigation are required, with risk of flush-

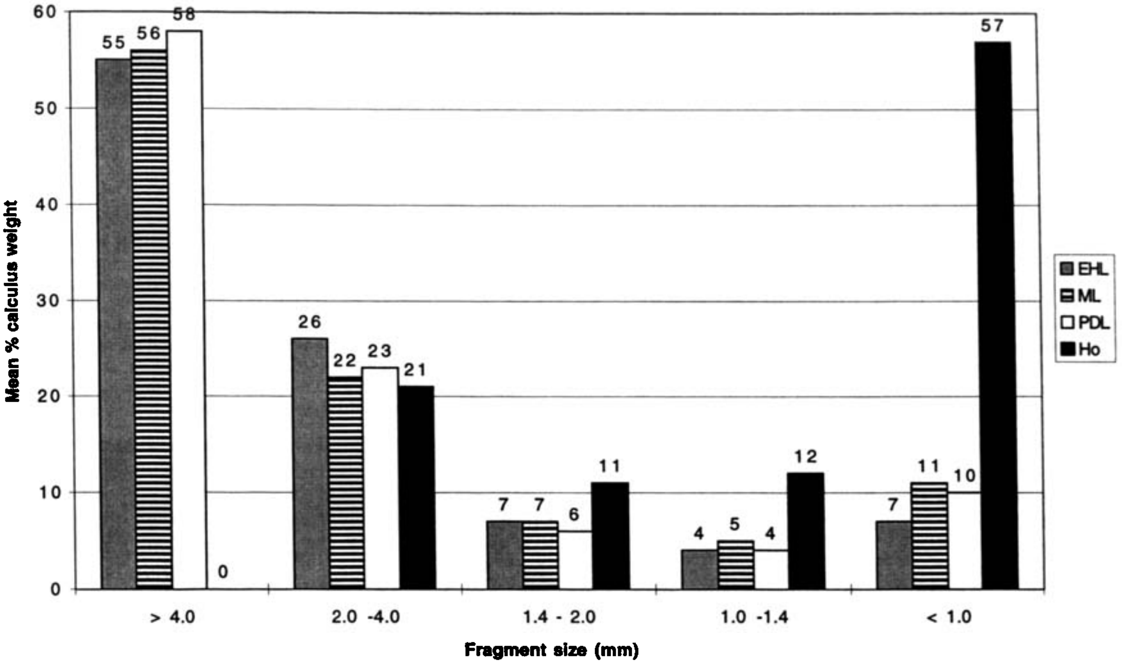

FIG. 4. Mean percent weight of fragments by lithotrite of stones greater than 4, 2.0 to 4.0, 1.4 to 2.0, 1.0 to 1.4 and less than 1 mm. for magnesium ammonium phosphate. Percent values are shown for each bar. Electrohydraulic lithotripsy (*EHL*), mechanical lithotripsy (*ML*) and pulsed dye lasers (*PDL*) fragments predominate for group greater than 4 mm., whereas holmium:YAG lithotripsy (*Ho*) fragments predominate for groups less than 1.0 and 1.0 to 1.4 mm. (p <0.001).

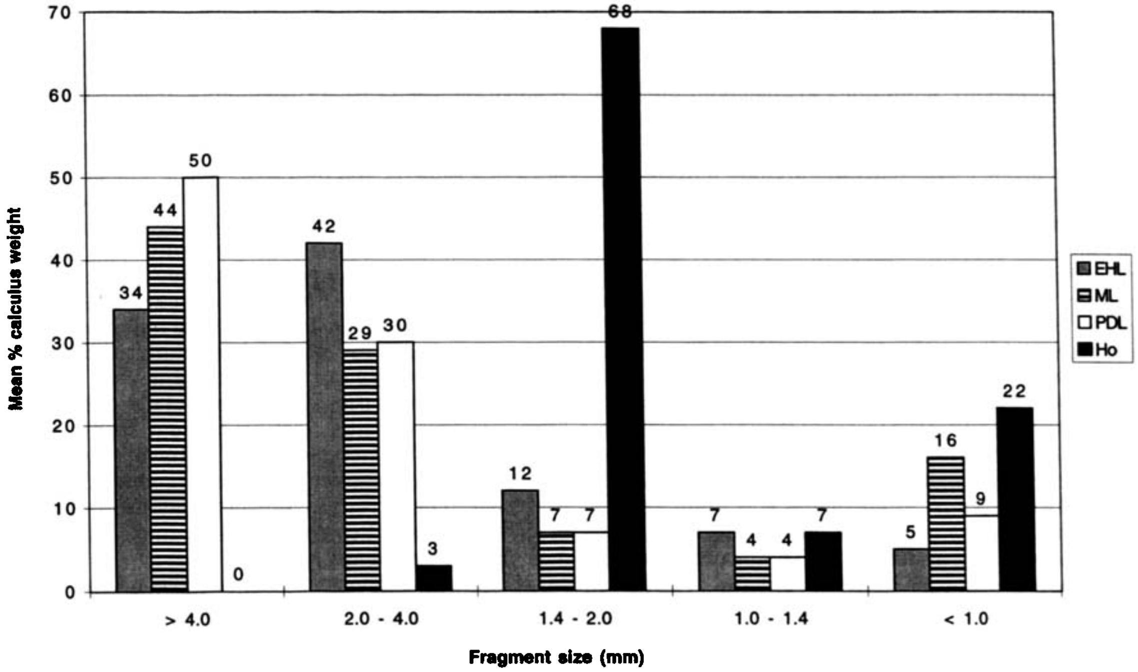

FIG. 5. Mean percent weight of fragments by lithotrite of stones greater than 4, 2.0 to 4.0, 1.4 to 2.0, 1.0 to 1.4 and less than 1 mm. for uric acid. Percent values are shown for each bar. Electrohydraulic lithotripsy (*EHL*), mechanical lithotripsy (*ML*) and pulsed dye lasers (*PDL*) fragments predominate for groups greater than 4 and 2.0 to 4.0 mm., whereas holmium:YAG lithotripsy (*Ho*) fragments predominate for groups 1.4 to 2.0 and less than 1.0 mm. (p <0.001).

ing fragments retrograde. The urologist then must chase the fragments or risk leaving behind residual fragments. Furthermore, the continued manipulation in the context of already inflamed mucosa risks further bleeding and ureteral perforation.[10] In contrast, holmium:YAG lithotripsy is not as likely to risk these problems. The stone debris is small and easily irrigated from the field. Little basketing is required since there are few large fragments. Given that there may be less risk of residual fragments, there is theoretically less risk of stone re-growth.[11] Endoscopic vision is not impaired since weak shock waves are unlikely to risk collateral mucosal injury that may occur with electrohydraulic lithotripsy.[12]

TABLE 3. *Computed size distribution*

	Mean ± SD (mm.)				p Value*
	Electrohydraulic Lithotripsy	Mechanical Lithotripsy	Pulsed Dye Lasers	Holmium:YAG Lithotripsy	
Calcium oxalate monohydrate	2.87 ± 1.16	2.93 ± 1.09	2.35 ± 0.99	1.82 ± 0.88	<0.001
Calcium phosphate	3.83 ± 0.59	2.88 ± 1.26	2.95 ± 1.07	1.50 ± 0.77	<0.001
Cystine	3.18 ± 1.13	3.00 ± 1.16	3.22 ± 1.03	1.62 ± 0.88	<0.001
Magnesium ammonium phosphate hexohydrate	3.25 ± 1.02	3.18 ± 1.11	3.22 ± 1.08	1.52 ± 0.80	<0.001
Uric acid	3.00 ± 1.16	3.18 ± 0.99	3.12 ± 1.05	1.55 ± 0.39	<0.001

* Pairwise differences at $\alpha < 0.05$ were electrohydraulic lithotripsy was different than pulsed dye lasers and holmium:YAG lithotripsy, mechanical lithotripsy was different than pulsed dye lasers and holmium:YAG lithotripsy, pulsed dye lasers was different than electrohydraulic lithotripsy, mechanical lithotripsy and holmium:YAG lithotripsy, and holmium:YAG lithotripsy was different than electrohydraulic lithotripsy, mechanical lithotripsy and pulsed dye lasers for calcium oxalate monohydrate; electrohydraulic lithotripsy was different than mechanical lithotripsy, pulsed dye lasers, and holmium:YAG lithotripsy, mechanical lithotripsy was different than electrohydraulic lithotripsy and holmium:YAG lithotripsy, pulsed dye lasers was different than electrohydraulic lithotripsy and holmium:YAG lithotripsy, and holmium:YAG lithotripsy was different than electrohydraulic lithotripsy, mechanical lithotripsy and pulsed dye lasers for calcium phosphate; holmium:YAG lithotripsy was different than electrohydraulic lithotripsy, mechanical lithotripsy, and pulsed dye lasers for cystine; holmium:YAG lithotripsy was different than electrohydraulic lithotripsy, mechanical lithotripsy, and pulsed dye lasers for magnesium ammonium phosphate hexohydrate, and holmium:YAG lithotripsy was different than electrohydraulic lithotripsy, mechanical lithotripsy, and pulsed dye lasers for uric acid.

The weak shock waves may also help to explain the clinical observation that there is little stone propulsion during holmium:YAG lithotripsy.[5,9,13]

Our data suggest that holmium:YAG lithotripsy may be a better lithotrite than electrohydraulic lithotripsy, pulsed dye lasers or mechanical lithotripsy. Cost of each of these lithotrites warrants consideration. Elashry et al summarized the significant cost differences among intracorporeal lithotripters, noting an advantage for electrohydraulic lithotripsy over holmium:YAG in capital, annual service contract, lithotriptor use/case and probe costs.[14] We previously addressed this comparison as relevant only if the high powered holmium laser (60 to 80 W.) were purchased and used solely for lithotripsy.[9] However, holmium:YAG also has soft tissue applications and it may be used for benign prostatic hyperplasia, strictures, urothelial tumors and condyloma.[15,16] At our hospital the dual wavelength holmium:YAG/neodymium:YAG laser is shared among urology, general surgery, orthopedics, and head and neck surgery, reducing the effective cost. Alternatively, if a urologist wished only to purchase a lithotrite, a low powered holmium:YAG unit (22 to 30 W.) has a comparable capital cost to mechanical lithotripsy. Holmium:YAG fibers are reusable so that effective probe cost may be lower than electrohydraulic lithotripsy or mechanical lithotripsy. Pulsed dye lasers have relatively expensive capital, annual service contract, lithotriptor use/case and probe costs.

There are 6 potential limitations to our study. 1) The study was done in a specimen container and not in vivo. Arguably, this design allowed us to isolate lithotrite effect on the stone itself rather than the confounding factors of renal, ureteral or bladder anatomy and/or inflamed mucosa. Clinically, irrigation during endoscopic intracorporeal lithotripsy would flush away the stone debris. Because stone debris was problematic for holmium:YAG lithotripsy more than other lithotrites, this issue would have actually handicapped holmium treated stones, since it may be argued that we did not fragment holmium treated stones as completely as was done for the other lithotrites. 2) The end point of lithotripsy for all calculi was when no further fragmentation occurred. At issue is whether this end point was subjective. Arguably, this end point may have strengthened the study. In a previous study to determine fragment size between different sized pulsed dye laser fibers the end point of laser lithotripsy was reached when the stone fell out of the basket or could no longer be fragmented within the basket.[17] We believed that in the clinical setting, if a stone were basketed and lithotripsy commenced followed by the stone falling out of the basket, the case would not be terminated. Rather, the urologist could choose then to re-basket the calculus and/or continue with lithotripsy. Thus, we thought that the end point of lithotripsy in our study should be to determine how well the lithotrite could fragment calculi. 3) The fraction of stone material recovered suggested that we did not recover as much holmium:YAG lithotripsy treated calculi compared to the other lithotrites (table 2). The likely explanation is that some particularly small stone debris (rather than big chunks) was lost either in discarding supernatant or in sublimation. In either case if collection were 100% then the data might favor holmium:YAG lithotripsy even further, since we believe that our current data underestimate the proportion of holmium:YAG lithotripsy fragments less than 1 mm. 4) Our data analysis assigned specific values when in actuality a range was measured. In anticipation of this issue, we assigned intermediate values for stones 1 to 1.4 (1.2), 1.4 to 2 (1.7) and 2 to 4 (3) mm. However, in anticipation of the outcomes that holmium:YAG lithotripsy would yield smaller fragments, we deliberately favored pulsed dye lasers, electrohydraulic lithotripsy and mechanical lithotripsy, and handicapped holmium:YAG lithotripsy by assigning all fragments greater than 4 mm. the value of 4 mm. and all fragments less than 1 mm. the value of 1 mm. Thus, the tendency towards error here actually was designed to favor the null hypothesis. The significant differences computed underestimate the magnitude of fragment size differences between holmium:YAG and the other lithotrites. 5) This study only demonstrated that fragment size differs. It did not compare stone-free rates. 6) We did not compare different fiber sizes within each lithotrite modality. At issue is whether the fragment size might vary as fiber size varies. One study revealed that mechanical lithotripsy probe displacement decreased as probe diameter increased.[18] A preliminary study compared results of a redesigned lithoclast versus the type of lithoclast used in our study.[19] Overall, the redesigned lithoclast appeared to have smaller probe displacement and smaller fragments compared to the older lithoclast. These results suggest that the larger probe displacement of smaller calibre mechanical lithotripsy probes may yield larger fragments.

In conclusion, holmium:YAG lithotripsy created the largest fraction of small fragments compared to electrohydraulic lithotripsy, mechanical lithotripsy and pulsed dye lasers. The average fragment for holmium:YAG lithotripsy was significantly smaller than for the other lithtorites.

David Fletcher and Louis C. Herring Co. contributed to this study, Dr. Gary M. Clark provided statistical assistance, and Melissa A. Garcia and Dr. Robert J. Klebe provided technical expertise.

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