LONG-TERM FEEDING OF HIGH ZINC SULFATE DIETS TO LACTATING AND GESTATING DAIRY COWS

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ABSTRACT

Thirty dairy cows, fed a control diet consisting of silage and concentrates, were given either 0, 1000, or 2000 ppm of supplemental Zn (DM basis), from zinc sulfate monohydrate (ZnSO₄·H₂O) for most of a lactation. Feeding 2000 ppm Zn decreased milk yield and feed intake after several weeks. Some cows were affected more severely than others. Generally, primiparous animals were more tolerant of the high Zn diet than multiparous cows. Milk Zn was materially higher for cows fed 1000 ppm added Zn than controls. With 2000 ppm Zn, milk Zn was elevated further but returned to control values when the high Zn diet was discontinued. Plasma Zn was higher in cows fed supplemental Zn with the increase from 1000 to 2000 greater than that for the first addition. Plasma Cu was lower in cows fed 2000 ppm Zn but milk Cu was not reduced. Milk fat content was not affected, but protein and SNF were reduced by the 12th wk with the 2000 ppm Zn diet. There was no apparent effect on long-term health or performance after the cows were removed from the 2000 ppm Zn diet. Except for lower calf weights with 2000 ppm Zn, reproductive performance was not measurably affected by the dietary treatments. The 1000 ppm added Zn diet had no adverse effect on the cows in any parameter measured.

INTRODUCTION

Zinc is an important element in the practical nutrition of animals. The maximum safe dietary intake is considerably higher than the requirement (13, 20). Feeding 1279 ppm Zn as zinc oxide (DM basis) for 6 wk (18) had no adverse effects on lactating dairy cows. Few data were available on the influence of long-term feeding of high Zn diets to lactating and gestating dairy cows. High concentrations of zinc sulfate denature proteins and can be used to increase the amount of rumen bypass protein (4). However, the maximum amounts of zinc sulfate that can be fed to lactating dairy cows without adverse effects over extended periods had not been established.

The first objective was to determine the maximum amount of Zn that can be fed as zinc sulfate to dairy cows for most of a lactation without adversely affecting milk production, health, or reproduction. A second objective was to study the effects when the maximum safe amount of Zn is exceeded. The third objective was to determine whether adverse affects of high dietary Zn are reversible.

MATERIALS AND METHODS

Thirty lactating Holstein cows were group-fed a preexperimental diet of concentrate plus wheat-arrowleaf clover silage for the first 5- to 8-wk postpartum. The preexperimental concentrate was composed of ground corn grain, 40.5%; rolled wheat, 29.5%; soybean meal, 21.6%; distillers dried grains, 7.2%; magnesium oxide, .1%; dicalcium phosphate, .3%;
TABLE 1. Ingredient composition of concentrate portion of experimental diets.¹

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Control</th>
<th>+ 1000 ppm Zn (%)</th>
<th>Control + 2000 ppm Zn (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground shelled corn</td>
<td>34.15</td>
<td>33.64</td>
<td>33.13</td>
</tr>
<tr>
<td>Rolled wheat</td>
<td>29.44</td>
<td>29.44</td>
<td>29.44</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>35.04</td>
<td>35.04</td>
<td>35.04</td>
</tr>
<tr>
<td>Magnesium oxide</td>
<td>.47</td>
<td>.47</td>
<td>.47</td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td>.40</td>
<td>.40</td>
<td>.40</td>
</tr>
<tr>
<td>Salt, trace-mineralized²</td>
<td>.50</td>
<td>.50</td>
<td>.50</td>
</tr>
<tr>
<td>ZnSO₄·H₂O³</td>
<td>.51</td>
<td>1.02</td>
<td></td>
</tr>
</tbody>
</table>

¹Feed grade.
²Contained: NaCl, 94 to 97%; Mn, .27%; Fe, .1%; Mg, 1%; S, .05%; Cu, .025%; Co, .01%; Zn, .008%; and I, .007%.

The zinc sulfate was mixed with the concentrate, which was then blended with silage and fed as a total mixed ration. The silage that was being fed to the university herd and was either wheat or sorghum. The cows were group-fed the concentrate-silage mixture, for ad libitum intake, allowing a 5 to 8% refusal. New feed was provided twice daily. Initially a 56.5:43.5 concentrate to silage ratio (DM basis) was offered. Based on NRC (20) values, the diet provided sufficient NEₜ for maintenance plus 40.5 kg milk of 3.5% milk fat. Similarly, protein was fed at 10% excess of requirement (20). The control diet of concentrates and silage mixed on a DM basis contained 1.04% K, .43% Ca, .37% P, .44% Mg, 55 ppm Zn, 310 ppm Fe, 13 ppm Cu, and 43 ppm Mn. Dry matter intakes of each group were determined on 2 consecutive d (d 11 and 12) every 2 wk throughout the experiment.

Milk production was determined daily during the preexperimental and experimental periods. Milk samples were taken at each milking during the last week of the preexperimental period and d 24 to 28 of each 28-d period for the remainder of the lactation. Milk samples were analyzed for Zn (9), SNF (6), fat (3), and protein (3). Solids-not-fat was the difference between total solids, as determined, and fat. Body weights were taken on 2 consecutive d of the first week postpartum, the last 2 d of the preexperimental period, d 27 and d 28 of each 28 d period thereafter, and on the last 2 d of the lactation.

During the experimental treatment period, blood samples were collected every 28 d from 5 randomly selected cows in each treatment group for Zn analyses. Each cow was clinically examined before being placed on treatment and every 28 d thereafter until the end of lactation.

After several weeks, most cows receiving the 2000 ppm Zn diet (total diet DM basis) began performing poorly, as indicated by decreased milk production. Therefore, in keeping with the third objective, when milk production
Figure 1. Milk production during first 16 wk of experimental treatment period. A) Values for cows fed control, 1000, and 2000 ppm diets. B) Best 5 and poorest 5 cows on 2000 ppm diet. The Zn-Zn group were fed 2000 ppm Zn throughout, whereas the Zn-Cont cows received 2000 ppm Zn for 14 wk and control diet thereafter. SE = Standard error of treatment means calculated from error mean square; A. n = 10 except wk 14 and 16 = 9.3. B. n = 5 except wk 16 where n = 4.

RESULTS

For 7 wk after the dietary treatments were initiated, milk production was not affected by either of the high Zn diets (P>0.05) (Figure 1A). However, beginning with the 8th wk, cows fed 2000 ppm supplemental Zn produced less milk than those fed 1000 ppm Zn (P<0.05). Average production of the highest Zn group continued to decline and was lower (P>0.05) than controls by wk 12.

The 2000 ppm added Zn affected milk production of some cows much more than others (Figure 1B). Generally, multiparous cows were much more sensitive to the highest Zn intake than primiparous cows (Figure 2C). In keeping with well-established concepts, first lactation cows fed the control and 1000 ppm diets tended to be more persistent than those with previous lactations (Figures 2A and 2B). When given 2000 ppm added Zn, milk yield of older cows dropped far more rapidly than that of first-calf heifers (Figure 2C). This effect was not noted in cows fed control or 1000 ppm added Zn (Figures 2A and 2B).

In keeping with the third objective, when all cows previously given the 2000 ppm Zn diet were fed the control diet for the 15th and 16th wk of the experimental treatment period, milk production did not decline further. Because of the dichotomy of effects, the 3 primiparous cows and the 2 multiparous cows that did not appear to have been affected substantially by the 2000-ppm Zn diet were returned to this highest Zn diet on wk 17. At least through wk 26, their milk production was not different from that of those fed the control or 1000 ppm.
Figure 2. Milk production during first 16 wk of experimental treatment period of 7 multiparous and 3 primiparous cows in each treatment group. With all cows fed control diet wk 15 and 16. A) Control; B) 1000 ppm added Zn; C) 2000 ppm added Zn diets. SE = Standard error of a treatment mean calculated from error mean square; n = 5 except for diets B and C for wk 16, n = 4 and 3, respectively.

Figure 3. Effect of feeding control, 1000 ppm added Zn, 2000 ppm added Zn, or 2000 ppm added Zn for 14 wk followed by control diet (cont-2) on milk production during A) whole experimental treatment period or B) wk 17 to end of lactation. SE = Standard error of a treatment mean calculated from error mean square; A. n = 7 to 7.5 except 5.5 for wk 32 and 40 and 2.5 for wk 36, B. n = 7 to 7.5 except 5 to 5.5 for wk 33 and 41 and 3 for wk 37.

added Zn diets (P>.05) (Figures 3A and 3B). After wk 26, average milk production was lower for cows fed 2000 ppm Zn than for controls or the 1000 ppm Zn group, but the effect was not significant (P>.05) due to high variability. In the 2000 ppm group 1 cow was turned dry in wk 32, 1 in wk 34, and 2 in wk 35. Three of these 4 turned dry were due to low production. During the same period, 2 of those formerly fed 2000 ppm were turned dry due to low production, but none were in the control or 1000 ppm groups.

Milk production of the five cows that had been fed 2000 ppm Zn but received the control from the 15th wk on recovered materially and then through wk 24 remained even, thus increasing relative to the other cows whose yield was dropping (Figures 3A and 3B).

Overall, feeding 1000 ppm of Zn as zinc sulfate did not have an effect (P>.05) on milk production during the experimental period (Figures 1A, 3). However, average milk production values were slightly higher for those fed the 1000 ppm diet.

Feed consumption of cows fed 1000 ppm Zn was not affected (P>.05) (Figure 4A). Howev-
er, feed intake of those given 2000 ppm added Zn was reduced ($P > .05$) with the effect very pronounced beginning the 10 wk. On a group basis, feed intake paralleled milk production. Because cows were group-fed, it was not possible to determine which cows were affected most. When cows that had received the 2000 ppm diet were returned to the control, their average feed intake was comparable to controls (Figure 4A).

Body weights of cows in the three groups were similar for the first 16 wk of the experimental period (Figure 4B). After the 2000 ppm group was divided, those continued on the highest Zn intake tended to lose weight relative to others, whereas those that were returned to the control diet seemed to gain relative to others (Figure 4B).

Milk fat percentage was not affected by the dietary treatments ($P > .05$) (Figure 5A). Protein and SNF contents of the milk were not affected by the feeding of 1000 ppm Zn ($P > .05$) (Figures 5B and 5C). However, both protein and SNF were lower in cows fed the 2000 ppm Zn diet ($P < .05$). This effect was evident on samples taken after wk 8. When these cows were returned to the control diet, over a few weeks both protein and SNF composition of the milk returned to values comparable with those of the controls (Figures 5B and 5C).

Plasma Zn and Cu values are shown in Figures 6A and 6B. Plasma Zn was elevated in cows fed 1000 ppm added Zn with most of the effect evident by wk 4 (Figure 6A). However, there was little further increase with time. With those fed 2000 ppm added Zn, plasma Zn was substantially higher ($P < .05$) beginning with the first sampling period (wk 4) of the experimental period. Plasma Zn of cows fed the 2000 ppm Zn diet, continued to increase through wk 32. The first plasma samples analyzed for Zn after the return from 2000 ppm Zn to control was for wk 20 (Figure 6A). By this time plasma Zn values were comparable to controls.

Plasma Cu content was not affected by feeding 1000 ppm added Zn through wk 24 ($P > .05$) (Figure 6B). However, there was some reduction for samples taken during wk 32 and 36. Plasma Cu tended to be lower in cows fed 2000 ppm added Zn (Figure 6B). Values obtained after the highest Zn cows were returned to the control feed were not different from those never fed high Zn ($P > .05$).

Plasma Zn content was not different between multiparous and primiparous cows with cows fed the control or 1000 ppm Zn diets ($P > .05$) (Figure 7A and 7B). However, during wk 9 to 12 and 13 to 16 the 2000 ppm Zn diet increased plasma Zn more in older cows than in first lactation cows ($P < .05$) (Figure 7C).

Milk Zn was substantially increased when 1000 ppm Zn was added to the diet ($P < .05$) (Figure 8A) with most of the effect evident on the first sampling period (wk 4). With 2000 ppm added Zn, milk Zn was further increased. There was little increase subsequently with either high Zn diet. When the cows that had been fed 2000 ppm Zn were returned to the control diet, milk Zn values returned to values comparable to controls (Figure 8A).

Milk Cu content was not affected by either of the experimental diets (Figure 8B) ($P > .05$). However, there was considerable variation on different weeks.

Figure 4. Effects of feeding control, 1000 ppm added Zn, 2000 added Zn, or 2000 ppm added Zn diet for 14 wk followed by control diet (cont-2). A) Voluntary dry matter intake. B) Body weights. SE = Standard error of a treatment mean calculated from error mean square; B. n = 9.3 to 10 except 7.5 for wk 24 and 4.8 for wk 32.
Packed cell volume, hemoglobin, plasma protein, mean corpuscular hemoglobin concentration, fibrinogen, white blood cell count, and white cell differentials were not affected \((P > 0.05)\) by the high Zn diets (Table 2). The lower mean packed cell volume and hemoglobin values of cows fed 2000 ppm Zn were primarily due to extremely low numbers for 1 cow.

No clinical abnormalities were detected in cows fed 1000 ppm added Zn. With cows fed 2000 ppm added Zn, there was some indication of diarrhea. However, this was a subjective determination as cows in all the groups occasionally exhibited loose feces. Physical parameters such as temperature, pulse, respiration, and rumen motility remained within normal limits for all cows. In the clinical examinations, special efforts were made to detect any indication of arthritis or joint abnormality or enlargement. None was detected. Except for 1 calf in the control group that was born dead, examination during the first 5 d revealed no birth defects or other abnormalities.

Cows that received 2000 ppm for 14 wk and then were returned to the control had more days dry \((P < 0.05)\) than those fed 1000 ppm Zn (Table 2).
LONG-TERM HIGH ZINC TO LACTATING COWS

Figure 7. Plasma Zn in cows (multiparous) and heifers (primiparous) fed A) control, B) 1000 ppm added Zn, or C) 2000 ppm added Zn. SE = Standard error of a treatment mean calculated from error mean square; n = 1.5 to 5.0.

3). Calf weights were lower from cows given 2000 ppm Zn for most of the lactation (P<.05) than for controls. This was not due to lower weights of calves from primiparous cows or sex of calf effect. Two of the 3 calves of cows fed 2000 ppm Zn were males and 1 was from a multiparous cow.

DISCUSSION

Results of this study show that lactating Holstein cows can be fed 1000 ppm of supplemental Zn as zinc sulfate without adverse effects on milk production, feed intake, body weights, animal health, or reproduction. Likewise, milk fat, protein, and solids-not-fat were not affected by 1000 ppm Zn. There was a moderate increase in plasma Zn and milk Zn content and possibly some reduction in plasma copper with the 1000 ppm diet.

Feeding 2000 ppm added Zn as zinc sulfate clearly exceeded the maximum safe limit. However, the adverse effects were not evident until several weeks after dietary treatments were initiated. This indicates that the mechanism(s) involved in the adverse effects took time to develop. The nature of the cause of the detrimental effects of excess Zn are not readily apparent form this research. Because both the reduction

Figure 8. Effect of feeding control, 1000 ppm added Zn, 2000 ppm added Zn, or 2000 ppm added Zn for 14 wk and then control (cont-2) on A) milk Zn or B) milk Cu both expressed on fresh weight basis. SE = Standard error of a treatment mean calculated from error mean square; n = 7.2 to 10 except 1.75 for wk 32.

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>1000 ppm added Zn</th>
<th>2000 ppm added Zn</th>
<th>Recovery after 2000 ppm added Zn</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packed cell volume, %</td>
<td>34.3 ± 1.16</td>
<td>33.4 ± 0.89</td>
<td>31.0 ± 1.39</td>
<td>33.0 ± 1.14</td>
<td>1.14</td>
</tr>
<tr>
<td>Hemoglobin, %</td>
<td>12.4 ± 0.39</td>
<td>12.0 ± 0.37</td>
<td>10.9 ± 1.04</td>
<td>12.1 ± 0.39</td>
<td>0.39</td>
</tr>
<tr>
<td>Plasma protein, %</td>
<td>7.9 ± 0.16</td>
<td>7.9 ± 0.13</td>
<td>7.3 ± 0.16</td>
<td>7.9 ± 0.16</td>
<td>0.16</td>
</tr>
<tr>
<td>MCHC 2</td>
<td>36.2 ± 0.39</td>
<td>36.0 ± 0.37</td>
<td>35.3 ± 0.37</td>
<td>35.6 ± 0.29</td>
<td>0.29</td>
</tr>
<tr>
<td>Fibrinogen</td>
<td>432 ± 12.9</td>
<td>470 ± 10.7</td>
<td>417 ± 10.7</td>
<td>425 ± 12.9</td>
<td>37</td>
</tr>
<tr>
<td>White blood cells (per ml)</td>
<td>11,171 ± 253</td>
<td>11,315 ± 253</td>
<td>11,236 ± 253</td>
<td>12,350 ± 253</td>
<td>1291</td>
</tr>
</tbody>
</table>

*None of the treatment differences for any measure were significant (P<0.05).
1Standard error of a treatment mean calculated from error mean squares (n = 6.2).
2Mean corpuscular hemoglobin concentration.

in milk yield and lower feed intake occurred at about the same time, it appears that excessive Zn causes a systemic effect.

Some cows were affected far more than others by the 2000 ppm Zn diet. However, with the less affected cows, data such as more cows going dry early due to low production and smaller calf weights are suggestive of some adverse effects of the 2000 ppm Zn diet. On an average, the primiparous cows were affected much less than multiparous individuals. Also, plasma Zn was elevated more by the 2000 ppm

TABLE 3. Reproduction data of cows fed control, 1000 ppm added Zn, 2000 ppm added Zn, or control after 2000 ppm added Zn for 14 wk.

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Control + 1000 ppm Zn</th>
<th>Control + 2000 ppm Zn</th>
<th>Recovery after 2000 ppm + Zn</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>No cows</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Days to first estrus</td>
<td>56.5 ± 1.70</td>
<td>43.1 ± 1.75</td>
<td>82.7 ± 1.00</td>
<td>47.0 ± 1.25</td>
<td>14.5</td>
</tr>
<tr>
<td>Services per conception 2,3</td>
<td>1.70 ± 0.05</td>
<td>1.75 ± 0.05</td>
<td>1.00 ± 0.05</td>
<td>2.25 ± 0.40</td>
<td>.40</td>
</tr>
<tr>
<td>Days open 2,3</td>
<td>122.3 ± 9.27</td>
<td>115.6 ± 8.43</td>
<td>102.7 ± 7.43</td>
<td>132.3 ± 10.56</td>
<td>24.2</td>
</tr>
<tr>
<td>Days dry 2,3</td>
<td>78.9 ± 4.99</td>
<td>67.4 ± 4.99</td>
<td>84.7 ± 4.99</td>
<td>105.8 ± 4.99</td>
<td>10.3</td>
</tr>
<tr>
<td>No. live calves born</td>
<td>9 ± 1.70</td>
<td>8 ± 1.70</td>
<td>3 ± 1.70</td>
<td>4 ± 1.70</td>
<td></td>
</tr>
<tr>
<td>Calf weight, kg</td>
<td>41.1 ± 2.01</td>
<td>37.5 ± 2.01</td>
<td>32.5 ± 2.01</td>
<td>37.2 ± 2.01</td>
<td>1.8</td>
</tr>
</tbody>
</table>

*Values in the same row having different letters differ (P<0.05).
1Standard error of a treatment mean calculated from error mean squares (n = 4.9).
2Includes only cows that subsequently calved.
3Of the 10 control cows, 9 gave birth to live calves and 1 to a calf dead at birth. One cow in the group fed 1000 ppm died of unknown causes with the necropsy inconclusive. Also in this group 1 cow was culled when she was dry and not pregnant. The other 8 cows fed 1000 ppm Zn gave birth to normal calves. One cow fed 2000 ppm Zn followed by control died of a lymphosarcoma that apparently was unrelated to the dietary treatment. Of the 5 cows fed 2000 ppm throughout, 2 were culled when they were still not pregnant after being turned dry.
4One calf in control group was born dead.

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diet in the multiparous animals (Figure 7C). The individuals whose milk production was most quickly and severely depressed by 2000 ppm Zn also had highly elevated plasma Zn. This suggests the possibility that the homeostatic mechanism for Zn may have been less effective in these animals. Alternative explanations of the detrimental influence of the 2000 ppm diet are possible, including adverse effects on palatability that might have lowered feed intake. The authors think this is less likely due to the long time it took for the 2000 ppm diet to have an effect. With beef calves 3000 ppm added dietary Zn sharply reduced feed intake beginning the 1st d (22). Likewise, high Zn concentrations lowered palatability during an 8-d study (22). Because the adverse effects of 2000 ppm Zn in our study did not affect feed intake or milk production for several weeks, it seems probable that palatability was not the major cause of the detrimental effects.

Much of the detrimental effect of feeding 2000 ppm added Zn disappeared soon after the diet was discontinued. The increased number of dry days is associated with reduced milk production. Also, more cows were lost due to not being pregnant with the 2000 ppm added Zn diet.

Because of several uncertainties, the data of this study are not sufficient to make a completely definitive determination as to whether all the systemic adverse effects of feeding 2000 ppm Zn were eliminated soon after the cows were returned to the control diet. These were all multiparous cows that initially had above average milk yields. As a percentage of preexperimen- tal values, their milk yields remained below the control and 1000 ppm cows. However, multiparous cows normally have lower persistency values than primiparous ones. Also, once lower milk yields persist for a sustained period, they generally do not fully recover in that lactation (13).

Early research with rats indicated that high intakes of Zn interfered with metabolism of other trace elements including Cu and Fe (10, 13, 21, 23). Feeding high Zn diets for an extended period lowers hemoglobin in ruminants (23). In this study, plasma Cu was reduced when 2000 ppm of supplemental Zn was fed. Thus, it seems important, when feeding 1000 ppm Zn, to feed Cu at somewhat above minimum requirements.

Although not significant (P> .05), there was a tendency for lower blood hemoglobin. This is a further indication that the 2000 ppm was only sufficient to impair the most susceptible measures (2, 21) of toxicity, such as milk production and feed intake. Performance and biochemical measures are affected before severe clinical changes are noted (21).

Zinc toxicity can cause bone and joint abnormalities and deformities including enlargement of the hock joint and nonspecific degenerative arthritis in horses (8, 11, 21) and an arthritis-like syndrome in swine (21). There was no indication of such abnormalities in this study.

The higher Zn content of milk in cows fed both 1000 and 2000 ppm added Zn should not be detrimental to consumers as Zn intake by large components of our population is at best only borderline adequate (15). Metabolism of Zn is quite different in calves and adult cattle (7). When fed 640 ppm Zn, organs of calves, such as liver and kidney, accumulate increased amounts of Zn (17, 19). This does not occur in cows fed the same concentration of dietary Zn (7). The differences in metabolism of Zn between lactating cows and younger animals are consistent with research showing that lactating cows have a higher tolerance for Zn than do younger cattle (13, 18, 20, 21, 22).

The Ca content of the diets used in this study were below NRC (20)-recommended amounts but sufficient to meet requirements shown to be adequate for maximum milk production (1, 13, 16, 20). Because of the mutual antagonism between Ca and Zn in some species (12, 13), the low Ca content of these diets may have decreased slightly the tolerance for the high Zn intakes. Thus, with the higher Ca diets usually fed to lactating dairy cows, the adverse effects of 2000 ppm added Zn might be lower than that observed in this study.

Other research indicates that the bioavailability of Zn as zinc sulfate and zinc oxide are comparable (12, 13, 14). Although long-term studies have not been done with zinc oxide, it seems probable that the maximum safe intake of Zn would be similar for Zn from the two sources.
Results of this research indicate that 1000 ppm supplemental Zn can be fed to lactating dairy cows for extended periods without adverse effects. Reductions in milk yield and feed intake can be expected after a period of time when 2000 ppm Zn is fed to lactating dairy cows. However, a substantial part of this detrimental effect appears to be reversible when the excess Zn is removed from the diet.

ACKNOWLEDGMENTS

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REFERENCES