CURRENT TOPIC

Biphosphonates

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Background

The bisphosphonates (previously referred to as biphosphonates or diphosphonates) are a group of agents which are analogues of pyrophosphate. When administered either orally or parenterally they are adsorbed onto hydroxyapatite crystals in bone mineral and, because their structure renders them resistant to enzyme degradation, they act principally by inhibiting bone resorption, although some effect on bone formation probably also occurs.[1] The net effect is to promote bone mineral accretion while at the same time considerably reducing bone turnover. Because of this latter effect, there have been concerns about the use of bisphosphonates in children in whom bone turnover is normally much greater than in adults. As a result, there have been fears that interference with the rapid remodelling process, which is necessary in growing bones, might result in bone deformity or serious disruption of the normal mineralisation process. The limited experience of their use has, so far, largely proved these fears to be groundless.

Wide experience of the use of bisphosphonates has been gained in adults, principally for the treatment of involutional osteoporosis, Paget's osteitis deformans, and the hypercalcaemia and bone pain of malignancy. Several hundred papers have been published on these topics, many of them as a result of properly controlled trials. In contrast, very few studies in children have been published.[2–25] These are all anecdotal and only one study included any control subjects.[15] Nevertheless, the limited experience of the use of bisphosphonates in children and adolescents which has so far been gained does suggest that, for some conditions such as osteogenesis imperfecta and perhaps juvenile osteoporosis, wider use is indicated and may provide a useful additional therapeutic measure.

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Pharmacology

The bisphosphonates are pharmacologically simple compounds that all have a phosphorus-carbon-phosphorus structure (compare with the phosphorus-oxygen-phosphorus structure of pyrophosphate). The presence of carbon rather than oxygen allows the addition of side chains to the carbon atom that determine the specific properties of any individual compound. Thus nitrogen is present in pamidronate, alendronate and neridronate, chlorine in clodronate and tiludronate, and sulphur in tiludronate. These alter the pharmacological profiles and influence the extent to which bone formation as well as bone resorption is inhibited. They may also determine side effects. Some bisphosphonate preparations are used after technetium labelling as bone scanning agents.

Little is known of the pharmacology of the bisphosphonates in children as no specific studies have been undertaken and all the information that is available has been obtained in adult subjects. They can be administered either intravenously or orally. If given orally, only a small proportion (about 2%) is absorbed, the rest remaining within the bowel lumen. The amount absorbed is dependent on the time of administration in relation to food and it is usually recommended that food is avoided for at least two hours before or after administration. However, bisphosphonates are readily soluble in water and can be made up in different strengths for paediatric use.

Only four agents, etidronate, pamidronate, clodronate, and alendronate have been given product licences in the UK. None of these is recommended for use in children and therefore no dosage schedules are available. In the published paediatric studies intravenous administration has been given daily for between one and 18 days in doses ranging between approximately 0.2 and 1.0 mg/kg/day. In some reports these doses have been repeated after three or six months, depending on the condition being treated. In others, the initial intravenous treatment has been followed by oral administration and oral treatment alone has also been used. The duration of oral treatment has varied from one to 83 months, but has mostly been for between six and 24 months either continuously or intermittently in doses approximately 20 to 40 times that of intravenous use (reflecting the poor bioavailability via the oral route).

Clinical usage

The conditions for which bisphosphonates have been used in children are more diverse than those of adults and can broadly be divided into four groups: those in which (1) there is a primary defect in bone mineralisation (for example juvenile osteoporosis); (2) bone matrix abnormalities are seen (for example osteogenesis imperfecta); (3) bone abnormalities result from systemic disease or the effects of treatment of systemic disease (for example

steroid treatment of juvenile chronic arthritis or immobilisation after severe neurological damage); and (4) there is significant soft tissue calcification with no significant bone abnormality (for example myositis ossificans or infantile arterial calcification). Three other conditions, hyperphosphatasia, Gaucher's disease and polyostotic fibrous dysplasia, with or without McCune-Albright syndrome, have also been treated and, for the purposes of this discussion have been placed in the second group. In addition, one patient who had primary oxalosis and one with malignant osteopetrosis were treated. Both of these have been placed in the third group. It should be noted that this classification is, to a certain extent, arbitrary and is intended to help clarify the uses of bisphosphonates. Furthermore, some conditions can be considered to fall into more than one group.

Primary defects in bone mineralisation

Juvenile osteoporosis is a rare condition that usually occurs in preadolescent children. The aetiology is unknown, although some degree of bone rarefaction may occur in association with other conditions (for example some forms of osteogenesis imperfecta). It is sometimes accompanied by mild hypercalciuria.[2 4] Diagnosis of juvenile osteoporosis therefore depends on exclusion of other causes of secondary osteoporosis. It is usually self limiting and shows a marked improvement during adolescence. However, although logic dictates that this is likely to be a suitable case for treatment, there are only three reports of the use of bisphosphonates in juvenile osteoporosis.[2–4] All three patients showed a marked improvement in symptoms on treatment with reduction in hypercalciuria, but assessment of the effect is extremely difficult in view of the natural improvement in the condition.[26] It should also be noted that, where these compounds have been used to treat postmenopausal osteoporosis, the initial increase in bone density showed a plateau effect after the first year. Furthermore, increased bone density does not necessarily equate to increased bone strength.

Primary bone matrix abnormalities

Osteogenesis imperfecta has been treated in six children.[3–6] In all cases improvement in fracture rate and increase in bone density occurred. In three of the reports this was the primary aim of treatment, but in the fourth,[4] clodronate had been used with some success primarily to reduce the excessive hypercalciuria that frequently occurs in poorly growing patients with osteogenesis imperfecta,[27] and may lead to nephrocalcinosis.

The bone lesions of Gaucher's disease have been treated with pamidronate in eight children.[3 7–9] In all cases there was a reduction in alkaline phosphatase (a measure of bone formation) and fracture rate and an increase in bone density. Similar responses to pamidronate were also seen in the one reported child with hyperphosphatasia,[10] and the two with fibrous dysplasia.[3 11] The latter study also included the treatment of eight adult women.

Bone abnormalities secondary to systemic disease

This forms the largest group of children (20) who have been treated with bisphosphonates. In most cases this resulted either from immobilisation (with or without hypercalcaemia) after tetraplegia,[12 13] or cerebral palsy,[14] or from steroid treatment of juvenile chronic arthritis.[3 15] One further child was treated for hypercalcaemia associated with acute leukaemia,[16] another had hypercalcaemia after immobilisation after a liver transplant,[17] a third had severe osteoporosis associated with congenital neutropenia,[18] a fourth girl with primary oxalosis was treated for hypercalcaemia after transplantation with either liver and/or kidney,[19] and a fifth child with malignant osteopetrosis was treated for hypercalcaemia after bone marrow transplantation.[20] In all cases hypercalcaemia, where present, was corrected and in many the osteoporosis improved.

Soft tissue calcification

The first report of the paediatric use of bisphosphonates was in three children with myositis ossificans.[21] One further report of their use subsequently appeared,[22 23] together with three reports of the treatment of severe infantile arterial calcification.[23–25] Both of these conditions are rare and either severely debilitating or fatal and in all cases soft tissue calcification regressed markedly, although the total duration of treatment is not always specified and the final outcome is not clear.

Adverse effects

The use of bisphosphonates in children appears to be relatively safe even when used for quite long periods. All of the preparations used have an influence on bone turnover and in those conditions in which increased turnover is present, this effect is desirable and is reflected in a reduction in plasma alkaline phosphatase. However, an increase in translucent areas in bone,[22] and widening of the growth plate,[11] have been reported and, in one instance of juvenile osteoporosis, there was an initial deterioration in spinal fractures before overall improvement occurred.[2] Transient hypocalcaemia, which may be symptomatic, can also be a problem, although this is only temporary.[10–12] Both of these effects are more likely to occur with intravenous than with oral treatment. It should also be noted that long term use of some bisphosphonates, particularly etidronate, can cause marked osteomalacia in adults, although this effect is less likely to occur with other compounds.

In rapidly growing bones, interference with bone remodelling may occur while treatment is being continued. This effect has been described as 'undertubulation',[3] and consists of a failure of remodelling of the wide growth plate into the narrower metaphysis as the growth plate itself advances. When treatment is discontinued, remodelling does then occur leaving a normally shaped bone with a dense line of mineralisation at the point where the growth plate was being formed during the time

of treatment. The increased density of bone which occurs during bisphosphonate treatment is largely seen at the points where bone mineralisation is occurring most rapidly,[2–9 11 14 15 18] but does not seem to lead to bone deformity. The one young patient described who had severe osteogenesis imperfecta type III did show quite a marked disruption of bone architecture,[4] but this was identical to the appearances seen in untreated osteogenesis imperfecta type III and has been described as 'popcorn bone' (F Glorieux, personal communication) and is unlikely to be a bisphosphonate effect.

Transient fever is recognised as a side effect of bisphosphonate treatment in adults and also occurs in children. However, it is an effect that is confined to the use of nitrogen containing compounds and has only been described with pamidronate.[10 12] Anterior uveitis, episcleritis, and transitory conjunctivitis have all been reported with the use of pamidronate, but only when used intravenously.[28] Transient myalgia, leucopenia, lymphopenia, and gastrointestinal disturbance may occasionally occur.[15] All of these effects are self limiting, although the ocular problems did recur if the patients were rechallenged.

Conclusions

Only very limited experience with bisphosphonates in children has been gained and most of the reports are either single or small numbers of case reports. The approach to treatment has been somewhat serendipitous and often in situations where a child is extremely ill. Nevertheless, the data which are available do suggest that bisphosphonates may be of value under certain circumstances, but the very real concerns about adverse effects will need to be addressed particularly as children may live for several decades after treatment has been instituted and it is necessary to ensure that long term problems do not arise as a consequence. This is best done by ensuring that proper monitoring of plasma and urine biochemistry, markers of bone turnover, bone density measurements and the results of treatment on growth are undertaken and are best done where these patients can be gathered together so that larger numbers of these rare conditions can be studied under more controlled circumstances than previously. It may also be appropriate to extend the studies to children whose problems of bone mineralisation are milder than those in whom bisphosphonates have hitherto been used. When treatment is being considered, informed consent from the parents and, if appropriate, the child needs to be obtained and an explanation given that none of the bisphosphonates is licensed for use in children and that knowledge of the long term safety is very limited.

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1 Tsuchimoto M, Azuma Y, Higuchi O, *et al*. Alendronate modulates osteogenesis of human osteoblastic cells in vitro. *Jpn J Pharmacol* 1994;**66**:25-33

2 Hoekman K, Papapoulos SE, Peters AC, Bijvoet OL. Characteristics and bisphosphonate treatment of a patient with juvenile osteoporosis. *J Clin Endocrinol Metab* 1985;**61**:952-6.

3 Van Persyn van Meerten EL, Kroon HM, Papapoulos SE. Epi- and metaphyseal changes in children caused by administration of bisphosphonates. *Radiology* 1992;**184**: 249-54.

4 Allgrove J. Bisphosphonates: paediatric indications—advantages and possible side-effects. *Proceedings—paediatric osteology. New developments in diagnosis and therapy.* Cologne, Germany, 5–7 October 1995. Excerpta Medica International Congress Series No 1105. Amsterdam: Elsevier, 1996:261–73.

5 Devogelaer JP, Malghem J, Maldague B, Nagant de Deuxchaisnes C. Radiological manifestations of bisphosphonate treatment with APD in a child suffering from osteogenesis imperfecta. *Skeletal Radiol* 1987;**16**:360-3.

6 Huaux JP, Lokietek W. Is APD a promising drug in the treatment of severe osteogenesis imperfecta? *J Pediatr Orthop* 1988;**8**:71-2.

7 Harinck HI, Bijvoet OL, van der Meer JW, Jones B, Onvlee GJ. Regression of bone lesions in Gaucher's disease during treatment with aminohydroxypropylidene bisphosphonate. *Lancet* 1984;**i**:513.

8 Bembi B, Agosti E, Boehm P, Nassimbeni G, Zanatta M, Vidoni L. Aminohydroxypropylidene-bisphosphonate in the treatment of bone lesions in a case of Gaucher's disease type 3. *Acta Paediatr* 1994;**83**:122-4.

9 Samuel R, Katz K, Papapoulos SE, Yosipovitch Z, Zaizov R, Liberman UA. Aminohydroxypropylidene bisphosphonate (APD) treatment improves the clinical skeletal manifestations of Gaucher's disease. *Pediatrics* 1994;**94**:385-9.

10 Cassinelli HR, Mautalen CA, Heinrich JJ, Miglietta A, Bergada C. Familial idiopathic hyperphosphatasia (FIH): response to long-term treatment with pamidronate (APD). *Bone and Mineral* 1992;**19**:175-84.

11 Liens D, Delmas PD, Meunier PJ. Long-term effects of intravenous pamidronate in fibrous dysplasia of bone. *Lancet* 1994;**343**:953-4.

12 McIntyre HD, Cameron DP, Urquhart SM, Davies WE. Immobilization hypercalcaemia responding to intravenous pamidronate sodium therapy. *Postgrad Med J* 1989;**65**:244-6.

13 Varache N, Audran M, Clochon P, *et al*. Aminohydroxypropylidene bisphosphonate (AHPrBP) treatment of severe immobilization hypercalcaemia in a young patient. *Clin Rheumatol* 1991;**10**:328-32.

14 Shaw NJ, White CP, Fraser WD, Rosenbloom L. Osteopenia in cerebral palsy. *Arch Dis Child* 1994;**71**:235-8.

15 Lepore L, Pennesi M, Barbi E, Pozzi R. Treatment and prevention of osteoporosis in juvenile chronic arthritis with disodium clodronate. *Clin Exp Rheumatol* 1991; **9**(suppl 6):33-5.

16 Boudailliez BR, Pautard BJ, Sebert JL, Kremp O, Piussan CX. Leukaemia-associated hypercalcaemia in a 10-year-old boy: effectiveness of aminohydroxypropylidene biphosphonate. *Pediatr Nephrol* 1990;**4**:510-.1

17 Profumo RJ, Reese JC, Foy TM, Garibaldi LR, Kane RE. Severe immobilization-induced hypercalcaemia in a child after liver transplantation successfully treated with pamidronate. *Transplantation* 1994;**57**:301-3.

18 Bishop NJ, Williams DM, Compston JC, Stirling DM, Prentice A. Osteoporosis in severe congenital neutropenia treated with granulocyte colony-stimulating factor. *Br J Haematol* 1995;**89**:927-8.

19 Yamaguchi K, Grant J, Noble-Jamieson G, Jamieson N, Barnes ND, Compston JE. Hypercalcaemia in primary oxalosis: role of increased bone resorption and effects of treatment with pamidronate. *Bone* 1995;**16**:61-7.

20 Rawlinson PS, Green RH, Coggins AM, Boyle IT, Gibson BE. Malignant osteopetrosis: hypercalcaemia after bone marrow transplantation. *Arch Dis Child* 1991;**66**:638-9.

21 Bassett CAL, Donath A, Macagno F, Preisig R, Fleisch H, Francis MD. Diphosphonates in the treatment of myositis ossificans. *Lancet* 1969;**ii**:845.

22 Rogers JG, Dorst JP, Geho WB. Use and complications of high-dose disodium etidronate therapy in fibrodysplasia ossificans progressiva. *J Pediatr* 1977;**91**:1011-4.

23 Meradjii M, De Villeneuve VH, Huber J, De Bruin WC, Pearse RG. Idiopathic arterial calcification in siblings: radiological diagnosis and successful treatment. *J Pediatr* 1978;**92**:401-5.

24 Vera J, Lucaya J, Garcia Conesa JA, Aso C, Balaguer A. Idiopathic infantile arterial calcification: unusual features. *Pediatr Radiol* 1990;**20**:585-7.

25 Thiaville A, Smets A, Clerex A, Perlmutter N. Idiopathic infantile arterial calcification: a surviving patient with renal artery stenosis. *Pediatr Radiol* 1994;**24**:506-8.

26 Smith R. Idiopathic juvenile osteoporosis: experience of twenty-one patients. *Br J Rheumatol* 1995;**34**:68-77.

27 Chines A, Petersen DJ, Schranck FW, Whyte MP. Hypercalciuria in children severely affected with osteogenesis imperfecta. *J Pediatr* 1991;**119**:51-7.

28 Macarol V, Fraunfelder FT. Pamidronate disodium and possible ocular adverse drug reactions. *Am J Ophthalmol* 1994;**118**:220-4.